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EFFECTS OF AIR POLLUTANTS ON TEXTILE FIBERS AND DYES

NORTH CAROLINA UNIVERSITY

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This document presents: (1) a comprehensive survey of the damaging effects of air pollutants - particulates, SO_x, NO_x, and ozone - on textile fibers and dyes, and (2) the results and assessment of a public opinion survey to primarily measure consumer awareness of the detrimental effects of air pollution on household textile products. Nearly 100 references are cited and many of the research investigations are detailed and discussed.

The survey found that air pollution represents a significant problem area for the textile industry and many consumers. Major individual problems include (1) excess soiling of fabrics, (2) loss-in-strength of cellulosic and nylon materials by acids derived from SO_x, (3) fading of certain dyed cellulosic, acetate, and nylon fabrics by NO_2 and/or ozone, (4) yellow discoloration of undyed white fabrics by NO_2, (5) fading of permanent press polyester/cotton fabrics by ozone, and (6) fading of certain dyed nylon carpets by ozone. The public opinion survey revealed that consumer awareness
of nylon carpets by ozone. The public opinion survey revealed that consumer awareness
of the major air pollution effects on household textile products is poorly established and generally lacking.

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EFFECTS OF AIR POLLUTANTS ON TEXTILE FIBERS AND DYES

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ABSTRACT

This document presents a comprehensive survey of the damaging effects of air pollutants (particulates, sulfur oxides, nitrogen oxides, and ozone) on textile fibers and dyes and the results and assessment of a limited-scale public-opinion survey, designed primarily to measure consumer awareness of the detrimental effects of air pollution on household textile products. Many research investigations are discussed in detail, and numerous references are cited.

The findings of the survey supported the contention that air pollution is a significant problem for the textile industry and for many consumers. Major problems on which the survey concentrated include: (1) excessive soiling of fabrics; (2) loss in strength of cellulosic and nylon materials by acids derived from sulfur oxides; (3) fading of certain dyed cellulosic, acetate, and nylon fabrics by nitrogen dioxide and/or ozone; (4) yellow discoloration of undyed white fabrics by nitrogen dioxide; (5) fading of permanent-press polyester/cotton fabrics by ozone; and (6) fading of certain dyed nylon carpets by ozone. The public opinion survey revealed that consumer awareness of the major air pollution effects on household textile products is not only poorly established but generally lacking.

Key Words: effects-materials, textiles, textile dyes, deterioration, discoloration, fading, soiling, particulates, nitrogen oxides, sulfur oxides, ozone, opinion surveys, social attitudes, consumer awareness.

EFFECTS OF AIR POLLUTANTS ON TEXTILE FIBERS AND DYES

CHAPTER 1

INTRODUCTION

In earlier clean air legislation and, more specifically, in the Clean Air Amendments of 1970, Congress directed the U.S. Environmental Protection Agency (EPA) to "conduct research on, and survey the results of other scientific studies on, the harmful effects on the health or welfare of persons by the various known air pollutants." Welfare effects cover a wide variety of different areas including the effects on soils, water, crops, materials and property, animals, visibility, and climate, as well as effects on economic values and personal comfort and well-being.

Damage to materials and property is an important part of welfare effects. In fact, the accelerated corrosion of some metals by sulfur dioxide (SO_2), the cracking of rubber by ozone (O_3), and the soiling of buildings, statuary, and personal property by particulates are all well-known examples of materials problems. The effects of air pollution on textile products are less familiar, but a cursory review of information on this subject indicates that such effects constitute a major problem. After such an initial investigation, materials-effects specialists concluded that, since textiles comprise 8 to 10 percent of the gross national product, a thorough study of air pollution effects on textiles was needed.

Consequently, EPA conducted a comprehensive survey to identify and document the adverse effects of air pollution on textile fibers and dyes. To support this effort, EPA awarded a contract (PH 22-68-2) to Dr. Victor S. Salvin, a recognized authority in this field. He collected information from a number of sources, including various fiber producers, fabric mills, and processors; dye and chemical specialty suppliers; apparel and home furnishing manufacturers; commercial and retail outlets; and trade associations. Also, he directed a limited scale public opinion survey, primarily to measure consumer awareness of the detrimental effects of air pollution on household textile products.

This document presents the results of the survey and, additionally, brings together all available technical information on the subject of air pollution effects on textile products, providing an up-to-date picture of the total problem. Further, it furnishes background data for use in establishing air quality criteria and for use in economic analyses. This report may also stimulate new ideas and approaches for future research. This publication, written in a semitechnical style, is intended to appeal to a wide range of readers, especially those associated with various textile interests.

CHAPTER 2

EFFECTS OF AIR POLLUTANTS ON TEXTILE FIBERS

PARTICULATE MATTER

Soiling

Unless fabrics are exposed to the abrasive action of wind-blown particles or are soiled with highly abrasive particles and repeatedly flexed, they are not directly deteriorated by soiling, a familiar (but aesthetically objectionable) process in which airborne particles settle on objects. The major impact of soiling results from the need for more frequent dry cleaning and laundering, which not only represent added expenses but, more importantly, hasten the day when fabrics are no longer serviceable. Each cleaning cycle subjects fabrics to abrasion, heat, and harsh detergents or solvents; all these stresses contribute to a progressive loss in fiber strength and, in some cases, a gradual loss in color. Thus, increased soiling represents an economic loss because of the need for more frequent cleaning, which in turn reduces the normal life expectancy of fabrics.[1]

Suspended particulate matter accounts for most of the soiling that takes place on fabrics. These particles, which for the most part range in size from 0.1 to 10 micrometers (μm) in diameter, soil fabrics by impinging on or adhering to their surfaces. Particles of less than 0.1 μm, however, may soil by entering the capillary spaces known to exist in fibers.

Particles deposit on fabrics in several ways, with the larger ones usually settling out under the influence of gravity. Often, fabrics behave like a filter in that particles are deposited on them as air sweeps through the interstices between fibers. Draperies and curtains may be soiled in this manner. A process known as thermal precipitation causes household furnishings to soil when their surface temperatures fall below ambient air temperatures, a common occurrence during the winter heating seasons. Fabrics made from most synthetic fibers acquire electrostatic charges and, as a result, attract airborne particles of opposite charge, producing troublesome "fog markings." The degree of soiling may be influenced by various factors, including temperature, relative humidity, wind speed, and the nature and size of particles, as well as the type of fiber, construction, and finish.

Although it indirectly results in physical damage to fabrics because of the need for more frequent cleaning and the use of harsh detergents, soiling may also affect fabrics in other ways. For example, unidentified components in soils appear to accelerate the photochemical breakdown of some textile fabrics. (Supporting research will be presented later.) Also, metallic components of soils may have diverse effects on fabrics, and some, such as iron and zinc, can serve as catalysts that promote the oxidation of sulfur dioxide (SO_2) into harmful acids.[2] Others, such as chromium, vanadium, and manganese compounds, are known to offer some degree of protection to fabrics against the damaging effects of sunlight. Soiled fabrics, therefore, may undergo less photochemical degradation than clean fabrics. Accordingly, the total effect of soiling is complex, the net damage to fabrics depending on the chemical composition of the soiling particles and the ambient environment.

Effects on Natural Fibers

Natural fibers consist mainly of the cellulosics (cotton and viscose rayon) and wool, but also include such fibers as silk, flax, hemp, and jute. (Viscose rayon is a man-made fiber, but because it is manufactured from wood

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pulp and has properties similar to those of cotton, it will be grouped with the natural fibers.) Research on the effects of airborne particles on natural fibers has been generally confined to cotton, mainly because cotton has been the workhorse of the textile industry, has many applications, and is less resistant to overall environmental degradation.

Scientists at the Shirley Institute in England made one of the earliest attempts to assess the amount of tendering that smoke-laden air produces in textile fabrics.[3] In a limited field study, they exposed lightweight cotton fabric samples to the prevailing atmosphere at a single site on the roof of the Shirley Institute building. The samples were sheltered from rain and direct sunlight. Exposure lasted 12 weeks (January to April 1954), and samples were withdrawn for testing at periodic intervals. The investigators did not measure pollution, but did note that soiling varied considerably during the exposure period. Prior to exposure and after each exposure interval, soiling, tensile strength, sulfuric acid content, and fluidity were measured on the cotton samples.

Fluidity, an important property of textiles, is essentially an indirect measure of a polymer's average molecular weight. Chemists measure fluidity by dissolving polymers in suitable solvents and measuring the fluidity (reciprocal of viscosity) of the resulting solutions. Scientists can make use of changes in fluidity to detect changes in a polymer's molecular weight. Thus, an increase in fluidity indicates a reduction in the average molecular weight of a polymer. Such chemical changes are important because they are accompanied by changes in tensile strength and other physical properties. For example, extraneous environmental factors such as sunlight, heat, and contamination cause some polymers to degrade chemically. Changes in fluidity measure this undesirable effect. Fluidity measurements also allow scientists to distinguish between chemical degradation and physical degradation resulting from biological attack. In both cases, polymers lose strength, but physical degradation is the result of ruptured fibers rather than changes in molecular structure. Thus, fluidity values for physically degraded fibers remain essentially constant, and loss in strength is attributed to biological factors.

Results of the Shirley Institute cotton exposure study showed that, as exposure proceeded, the cotton samples became dirtier and progressively lost strength; fluidity increased, indicating chemical degradation; and sulfuric acid content increased during the first 8 weeks and then dropped off slightly. After 12 weeks, the cotton samples lost 59 percent of their original strength. Despite these results, the full significance of this limited study is clouded because the investigators did not simultaneously expose control samples to clean air at similar conditions of temperature, humidity, and sunlight. Without controls, pollution damage can not be separated from weathering damage. Nevertheless, the sulfuric acid content of the exposed samples indicates that acid probably caused much of the degradation. It is not known whether this acid resulted from the hydrolysis of inorganic sulfate particles or whether it came from airborne acid-aerosols. Notwithstanding the shortcomings of the study, however, the results strongly suggest that air contaminants were important contributors to the chemical degradation of the exposed cotton samples.

Rees[4] conducted several studies in which he assessed various factors that affect soiling. He exposed a series of scoured and bleached woven cotton fabrics to circulating air containing a controlled amount of dispersed activated-charcoal powder. Fabric construction varied from open porous plain cloth to tightly woven canvas material. The study revealed that airborne particles deposited more readily on porous open-weave fabrics than on closely woven low-porosity fabrics. In his study of textile soiling by thermal precipitation, Rees showed that the greater the temperature difference between fabric surfaces and ambient air, the greater the extent of soiling. He also investigated electrostatic soiling and found that soiling is heavier on positively charged fabrics (indicating a surplus of negative airborne ions) than on those charged negatively, with both showing much greater soiling than uncharged fabrics.

Morris and Wilsey[5] studied the effect of three soiling agents on the photochemical degradation of cotton. They impregnated some cotton yarn samples with an airborne soil, some with ground soil (clay, loam), and some with lignin derived from the organic portion of the ground soil. The yarn samples impregnated with airborne soil retained enough soil to increase the weight of the yarn about 5 percent. A group of soiled samples, along with unsoiled controls, were exposed in a Fade-Ometer (carbon-arc light source) for 640 hours. The investigators also aged a similar group of samples for 640 hours at 21°C in the absence of ultraviolet light. Degradation was evaluated by measuring the fluidity and breaking strength of the yarn samples. Fluidity values for the aged samples, both soiled and unsoiled, did not differ, thus showing that the soil treatments did not accelerate degradation. Of the samples exposed in the Fade-Ometer, however, those impregnated with airborne soil showed a 17 percent increase in fluidity over the unsoiled control samples. This result suggests that some component in the airborne soil accelerated the photochemical degradation of the cotton fibers by serving as a photosensitizing agent. Fluidity values for the samples impregnated with lignin and ground soil were essentially the same as for the unsoiled control samples, thus lignin and ground soil produced no photosensitizing effect. Although increases in fluidity are normally accompanied by losses in breaking strength, this study did not follow this pattern. The investigators found no significant differences in strength between the soiled and unsoiled samples for either the aged samples or those exposed to ultraviolet light in the Fade-Ometer.

Morris and Young[6] followed up the Fade-Ometer exposures with a field study. They impregnated cotton yarn samples with the same airborne soil that accelerated the photochemical degradation of cotton during the Fade-Ometer exposures. These soiled samples, along with unsoiled control samples, were mounted in a glass-covered cabinet, designed to allow free access of ambient air, and were exposed outdoors (in Berkeley, California) for four consecutive 3-month periods (84 days), as well as consecutive combinations of these periods. Some samples were exposed to direct sunlight while others were shaded. The investigators assessed degradation by measuring fluidity and breaking strength of the cotton samples. Table 2-1 presents data for the various exposure periods. During exposures to sunlight (unshaded conditions), the soiled samples underwent a significantly greater increase in fluidity than the unsoiled samples, thus confirming the photosensitizing effect (of this particular airborne soil) found during the Fade-Ometer exposures. In contrast, measurements showed little difference between fluidity of soiled and unsoiled samples shaded during exposure. Exposure to sunlight also showed that the soiled samples developed a greater loss in breaking strength than the unsoiled samples. The Fade-Ometer results did not show any difference in strength between soiled and unsoiled samples. Sample size did not permit breaking-strength measurements on shaded samples. By comparison, the 3-month outdoor unshaded exposures were more severe than the Fade-Ometer exposures (640 hours). Since in both exposures the investigators exposed the samples to about the same number of light-hours, the increased severity may have been caused by greater intensity of sunlight, or by some spectral component in the sunlight that is missing from the carbon-arc light source, or by a combination of these factors. Both exposures clearly show, however, that the airborne soil used by the investigators accelerated the degradation of cotton when it was exposed to ultraviolet light.

Table 2-1. CELLULOSE FLUIDITY AND BREAKING STRENGTH FOR COTTON YARN EXPOSED OUTDOORS

Exposure period	Number of days	Cellulose fluidity, rhes[a]				Breaking strength, g	
		Unshaded		Shaded		Unshaded	
		Soiled	Unsoiled	Soiled	Unsoiled	Soiled	Unsoiled
Jan-Mar	84	17.46	9.78	3.12	2.65	298	348
Apr-Jun	84	18.82	13.32	2.48	4.46	246	296
Jul-Sep	84	20.38	14.54	3.59	5.82	248	274
Oct-Dec	84	17.14	10.64	2.85	3.76	280	335
Jan-Jun	168	29.20	20.31	5.26	6.75	152	202
Jan-Sep	252	35.66	27.06	11.65	12.62	78	144
Jan-Dec	336	38.54	32.37	14.96	18.70	59	97
Control	-	0.58				599	

[a] Reciprocal poises.

Morris et al.[7] also studied the effect of airborne soil on the photochemical degradation of wool. The soil was similar to that used in the previously described cotton exposures. After treatment with the soil, the wool samples were said to have a "lightly soiled appearance." Results indicated that the soil had a moderate photosensitizing action on the wool. For example, after 160 hours of exposure in a Fade-Ometer, the soiled material had decreased 63 percent in strength, compared with 51 percent for the unsoiled material. The strength of soiled and unsoiled wool samples did not appreciably change when these samples were exposed in the dark for 160 hours under standard conditions (65 percent relative humidity, 21°C).

Window curtains and draperies are particularly vulnerable to environmental deterioration because they are subjected during their use to more destructive conditions than most fabrics.[8] While these items are woven from practically any fiber or combination of fibers, much of the observed accelerated deterioration has occurred to cellulosic fabrics. Deterioration and yellow streaks develop mainly along the exposed outer folds of curtains and draperies. Much of this damage is caused by sunlight, but an important contributing factor is air pollution, including particulate pollutants.

Effects on Synthetic Fibers and Blends

Because of public acceptance of and demand for synthetic fibers, the textile industry now consumes more fibers of this type than cotton. This consumption is due mainly to the high-volume use of nylon and polyester fibers. With increased consumption of synthetic fibers, soiling problems are of even greater importance because normal laundering does not remove soil from most synthetic fibers as easily as from natural fibers.

Man-made fabrics are more difficult to clean because of the nature of fibers themselves. Most natural fibers, such as cotton and wool, are hydrophilic and, thus, readily absorb detergent solutions, which emulsify and disperse the soil. On the other hand, most synthetic fibers are hydrophobic and, thus, do not readily absorb detergent solutions. Soil removal is difficult with synthetic fibers, therefore, since surface oil and soil are not easy to emulsify or suspend unless detergents properly wet the fibers.

Sooty soils are particularly troublesome because they are tenaciously bound to fiber surfaces. These soils, which contain unsaponifiable hydrocarbons, are typically found in Los Angeles-type air pollution. Sooty soils are not easily removed from man-made fibers by laundry detergents but may yield to dry cleaning. Nylon, despite repeated laundering, takes on a yellowish cast when exposed to such soils.[9]

Most synthetic fibers have another disadvantage that contributes to the soiling problem. Unlike natural fibers, man-made fibers have properties of high electrical resistance and low moisture absorption. They, therefore, easily acquire electrostatic charges by means of friction and become soiled by attracting oppositely charged airborne particles. The degree of soiling by this mechanism depends on the nature of airborne particles, the type of fiber, the surface topography of the fiber, and the finish applied to the fabric.

The popular permanent-press fabrics of polyester and cotton contain finishes that enhance various fabric properties. Finish components include shape-retention resins, softeners, catalysts, and soil-release (wetting) agents. Unfortunately, most of the finish components attract soil particles and hold them tenaciously. This factor, together with the electrostatic attraction that polyester fibers possess, intensifies the overall soiling problem for these important fabrics.

Soiling problems associated with man-made fibers have been the subject of considerable research. To reduce the soiling tendency of these fibers, scientists are continually experimenting with fiber modifications and searching for effective soil-release finishes.

Morris and Mitchell[10] studied the effect of an airborne soil on the photochemical degradation of nylon 66 yarn. Using an airborne soil similar to that used in previously described cotton studies, the investigators found that the soil had a slight photosensitizing action on the nylon. Upon exposure in a Fade-Ometer for 160 hours, the soiled nylon yarn lost 71 percent of its original strength while the unsoiled samples lost 62 percent. After exposure for 320 hours, the soiled yarn lost 86 percent of its strength while the unsoiled samples lost 81 percent. Control samples aged in darkness under standard conditions (65 percent relative humidity, 21°C) for like exposure periods showed no significant loss in strength. Control samples heated for like exposure periods in a circulating air oven at 63°C (the mean operating temperature of the Fade-Ometer) also showed no significant loss in strength. While the study clearly showed the pronounced damaging effect of ultraviolet light on nylon, the study also showed that this particular soil mildly accelerated photochemical degradation.

SULFUR OXIDES

Sulfur dioxide (SO_2) is a gaseous byproduct formed during the combustion of fuels containing sulfur and is a major atmospheric pollutant. Industrial operations and power plants are the principal sources of SO_2 emissions.

Effects on Natural Fibers

The known sensitivity of cellulosic fibers to acid deterioration has prompted a number of researchers to investigate the possible damaging effects of atmospheric contaminants. Interest has centered mainly on SO_2 because of its eventual conversion to sulfur acids. These acids have been responsible for reducing the life expectancy of clothes and of such household items as curtains, carpets (backing yarns), and linen products.[11]

One of the earliest (1928-29) studies on the damaging effects of air pollution on textile fabrics was an investigation by Wilkie[2] to determine why laundered cotton fabrics that were dried outdoors in winter in New England frequently underwent excessive deterioration. This peculiar problem had been of concern to residents of New England for a number of years and had come to be known as "winter damage." Deterioration occurred only in New England and only in the winter and was largely unpredictable. After examining many case histories, Wilkie concluded that winter damage was caused by sulfuric acid formed in the damp fabrics by oxidation of absorbed SO_2, which was present in the ambient atmosphere. Oxidation is accelerated by trace amounts of certain substances such as iron, spent bleach, and acetic acid, all of which may occur in laundered fabrics. As fabrics dry, the acid becomes concentrated in the areas that dry last. Subsequent ironing causes rapid deterioration and the fabric becomes weak. Damage occurs in winter because SO_2 from burning fuel is more prevalent then and because clothes do not dry well on cool, damp, or overcast days; thus, they remain moist longer and absorb more SO_2. Winter damage is found principally in New England because the water is exceptionally soft and, therefore, free from bases that would neutralize acids. Wilkie was able to reproduce various degrees of winter damage in the laboratory by exposing cotton fabrics, with and without special treatments, to repeated drying-ironing cycles. The drying operation consisted of exposing moist fabrics for about 24 hours to air initially contaminated with 2620 micrograms per cubic meter ($\mu g/m^3$) SO_2, or 1 part per million (ppm).

In the mid-1940's, Race[12] conducted several field studies in which he exposed cotton yarn samples (unprotected) to ambient air in the highly industrialized city of Leeds, England. He first exposed yarn during 3 consecutive summer months (June, July, and August), followed by a similar exposure the following winter (December, January, and February). For each seasonal exposure, breaking strengths were measured after 4, 8, and 12 weeks. The results showed that the cotton yarn underwent greater degradation in winter than in summer. Inasmuch as sunlight has a strong deteriorating effect on cotton, these results suggested an apparent anomaly because sunlight is more intense and the number of sunlight hours is greater in summer than in winter.

Race next exposed yarn samples at the same site on a monthly basis for 1 year. He again found a greater loss in breaking strength during the winter months (about 23 percent) than during the summer (about 17 percent). Furthermore, the smallest strength losses (about 15 percent) occurred in the spring and fall. Race also found an apparent relationship between monthly strength-loss values and the corresponding monthly pH measurements of both rainfall and the atmosphere. On the basis of these results, Race concluded that sulfuric acid aerosols, derived from SO_2 discharged into the atmosphere by domestic coal-burning heating systems, were responsible for the excess damage. The frequent accumulation of fog during winter further intensified the hostile nature of the atmosphere, since fogs prevent dispersion and allow contaminants to concentrate in the vicinity of the sources. In support of his conclusion, Race estimated that domestic and industrial coal-burning sources in Leeds release almost three times as much SO_2 in winter as in summer. He did not, however, actually measure the levels of SO_2 in the atmosphere.

Pomroy and Stevens[13] investigated the effects of nonspecific air pollution on the deterioration of drapery lining materials. The materials included four cotton and two acetate-rayon fabrics purchased at several large department stores. Two geographically different exposure sites were selected: Tallahassee, Florida, which has no industrial pollution but has a humid climate and receives intense sunlight; and Charleston, West Virginia, which is an industrial city—with much air pollution—located in a valley amid mountains. The investigators exposed the fabric samples both indoors and outdoors for four consecutive 3-month seasonal periods (May 1960 through April 1961), and also exposed them for cumulative periods of 6, 9, and 12 months. Deterioration was assessed by measuring breaking strength, with the results expressed as a percentage of the original breaking strength retained.

During the seasonal outdoor exposures, fabrics underwent a greater loss in strength in Charleston than in Tallahassee, despite the more intense sunlight in Tallashassee (Table 2-2). Deterioration was greatest in summer (May through July) and least during winter (November through January), which was contrary to what Race found. Race's findings, however, may be explained by noting that sunlight in England is less intense because of latitude, and pollution levels are far more severe in winter than in summer; air pollution levels in Charleston are fairly consistent throughout the year. Furthermore, in making site-to-site comparisons of the exposure results, the investigators recognized that weather conditions for the most part were dissimilar and that their analyses, therefore, were subject to some degree of uncertainty. They attempted to make these comparisons more valid by including in their analyses background information obtained from weather bureaus. Despite the differences in weather, the investigators concluded that the industrial air pollution prevailing in Charleston was a significant factor in causing the drapery lining materials to deteriorate during the outdoor exposures. The indoor exposure results, however, were generally erratic, although air pollution appeared to be a factor in the cumulative exposures of cotton fabrics (but not acetate-rayon) when sunlight was minimal.

Table 2-2. BREAKING STRENGTH OF COTTON FABRICS SEASONALLY EXPOSED OUTDOORS IN TALLAHASSEE AND CHARLESTON[13]

Exposure site	Breaking strength retained, percent			
	May-July	August-October	November-January	February-April
Tallahassee	58	73	79	74
Charleston	40	56	63	53

Although they concluded that air pollution was a significant factor in causing deterioration, the investigators did not measure air pollution or attempt to single out which pollutant or pollutants were causing most of the damage. The latter would admittedly be difficult because the nature of pollution in Charleston is known to be complex. On the basis of documented pollution measurements, however, one may surmise that acids, both inorganic and organic, caused much of the damage; acids are known to be detrimental to cellulosics. Sulfuric acid, resulting from the hydrolysis of sulfate particles, may have been the major culprit since sulfate particles make up about 11 percent of the total particulate matter found in the ambient air of Charleston.[14] Airborne sulfate particles are normally the end products of a series of atmospheric reactions involving SO_2.

Noting that some textile fabrics exposed at outdoor sites having equal sunlight intensity lost more strength at urban and industrial sites than at rural sites, Little[15] postulated atmospheric SO_2 as a possible cause and conducted simple tests to assess this supposition. He exposed sealed jars containing cotton samples to sunlight. The relative humidity inside the jars was 90 percent, and some jars contained a small quantity of SO_2 (amount not specified) while others contained clean air. The cotton samples in jars containing SO_2 developed considerable deterioration (evidenced by an increase in fluidity) after only a few days of exposure to sunlight; samples kept in darkness did not deteriorate (Table 2-3).

Table 2-3. EFFECT OF SULFUR DIOXIDE AND SUNLIGHT ON COTTON FABRIC SAMPLES

Exposure time	Increase in fluidity[a]	
	Clean air	Air containing SO_2
Kept in darkness	0	0.2
Exposed for 4 days	1.8	11.8
Exposed for 10 days	3.5	18.4

[a] The published research does not state the units, but normally fluidity is expressed as rhes (reciprocal poises).

These results prompted Little[15] to carry out indoor-outdoor exposures of bleached cotton fabrics at an urban site known to be contaminated with SO_2. Five month results showed that the rate of degradation for the outdoor samples was three times that of the indoor samples, but pH values (about 3.6) for both samples were similar. Little concluded that, while these pH values were low, they were not low enough to indicate the presence of sufficient amounts of strong acid to produce the degree of degradation measured. He proposed that acid attack was an unlikely cause of increased degradation and that sunlight, therefore, does not activate acid hydrolysis of cellulosics. Since the accelerating effect of sunlight must involve some other reaction, Little proposed that sunlight stimulates the oxidation of sulfur dioxide (SO_2) to sulfur trioxide (SO_3), and that SO_3 accelerates the normal photochemical oxidation of cellulose by atmospheric oxygen.

In the fall of 1961, Little and Parsons[16] conducted a field study in which they exposed cotton, nylon, and polyester fabrics at eight sites in the United Kingdom. The nominal weights of the fabrics were similar, and all were unprotected during the 12-month outdoor exposure period. Results, in terms of loss-in-strength measurements, varied considerably with location. At rural clean-air sites, cotton was more resistant than nylon, but roughly equivalent to polyester. In urban and industrial areas, however, polyester and, to a lesser extent, nylon retained more strength than cotton. Although air pollution was not measured, it is well-known that most English industrial areas have above average levels of air pollutants, including SO_2, which conceivably, could have played an important role in the deterioration of the cotton fabrics. Pollution in the form of particulate matter, however, can have a beneficial effect by reducing the amount of transmitted ultraviolet light. In reviewing this exposure study, Clibbens[17] observed that cotton had a greater range of deterioration than the synthetic fabrics. Moreover, he noted that polyester deterioration tended to be related to the amount of transmitted light energy, but that it was not significantly related to ambient air pollution. For nylon, the relationship between deterioration and light energy was less positive, and air pollution, therefore, may have exerted a small effect.

In further attempts to assess the role air pollution plays in degrading cotton textile fibers, Brysson et al.[18] conducted outdoor exposure studies that allowed the investigators to define more precisely the relationship between degrees of damage and corresponding ambient air quality. They exposed cotton fabrics at selected sites within metropolitan areas. Pollution levels differed from site to site, and, at most sites, one or more parameters of pollution were simultaneously measured during exposure. Because exposures were conducted within one metropolitan area, the scientists considered all sites to be similar meteorologically. This approach permitted the investigators to assume that the damaging effects of sunlight and other weather factors were essentially uniform at all sites. Data from nonpolluted control sites, therefore, became baselines for damage comparisons, and all damage found to be greater than that measured at control sites was attributed to air pollution. In an effort to minimize the degrading effect of sunlight, the exposure racks were oriented facing north at all sites.

Brysson et al.[18] conducted separate studies in the metropolitan areas of St. Louis, Missouri; and Chicago, Illinois. Exposures in both cities lasted 12 months, and fabric samples were periodically removed at specified intervals and tested. In both studies, the investigators found an apparent relationship between air pollution and loss in strength. The most deterioration in samples occurred at heavily polluted sites and the least occurred at the low-pollution sites. Additional support for the relationship between air pollution and sample deterioration was provided when it was shown that biological agents played an insignificant role in causing degradation. Figures 2-1 and 2-2 graphically illustrate the relationship between exposure time and strength retention for cotton fabrics that showed the most and the least loss in strength.

Brysson et al.[18] also attempted to correlate losses in strength with individual pollutant measurements. Pollution data for St. Louis included periodic 24-hour measurements of suspended particulate matter and monthly dustfall and sulfation measurements. (Sulfation measurements provide a useful index of the activity of atmospheric sulfur compounds, especially SO_2.) The investigators found a strong correlation (based on six observations) between retention of breaking strength and sulfation (Figure 2-3). For the heavier cotton duck cloth, the correlation coefficient for the 12-month exposure was 0.95. The correlation coefficient for the thinner cotton print cloth was 0.96; this value is based on 5 months of exposure since this period was the longest for which samples from all sites had a measurable degree of retained breaking strength. The relationship between deterioration and suspended

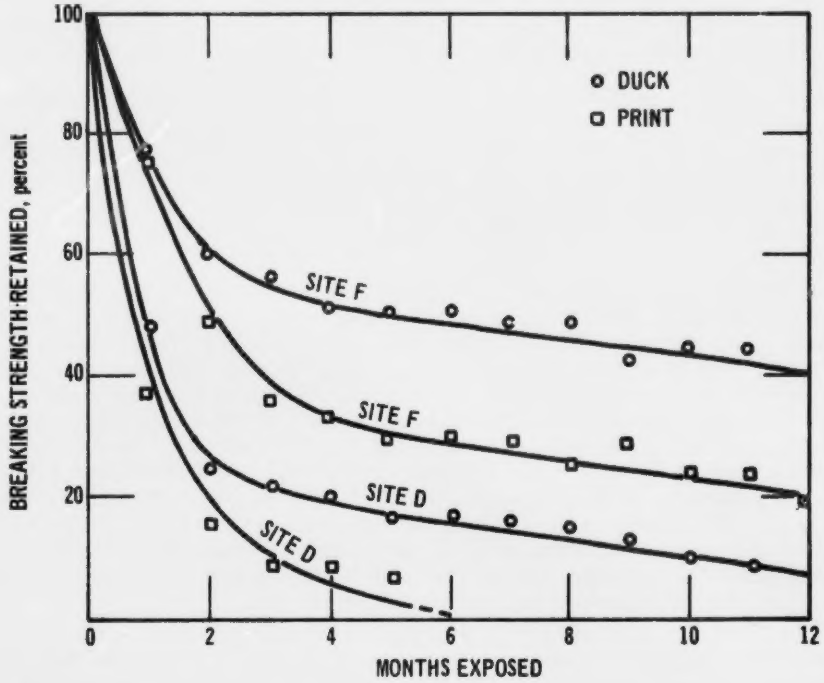

Figure 2-1. Strength retained on exposure of cotton print and duck fabrics at the most (site D) and least (site F) polluted sites in St. Louis.

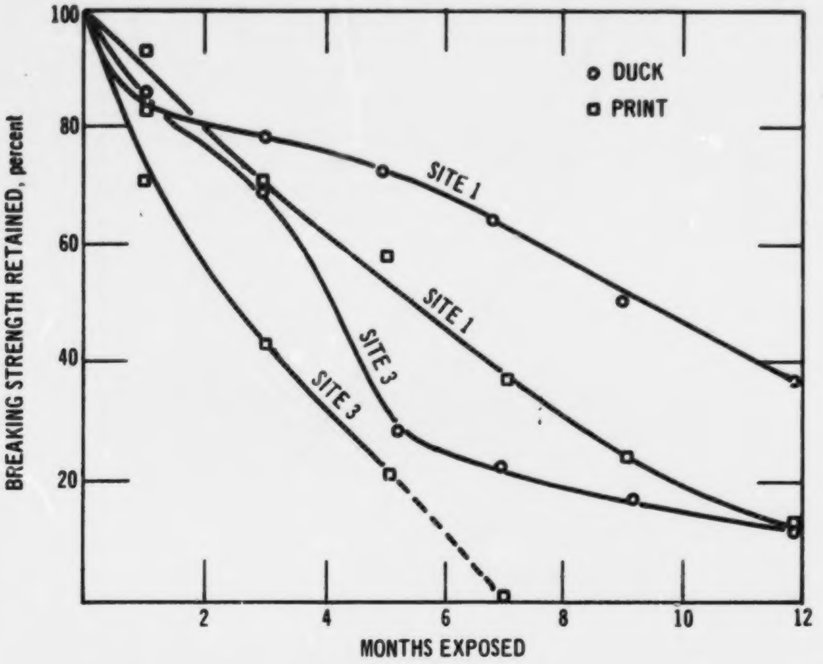

Figure 2-2. Strength retained on exposure of cotton print and duck fabrics at the most (site 3) and least (site 1) polluted sites in Chicago.

particulate matter, while substantial, was more scattered than that between deterioration and sulfation. No correlation was found for dustfall and deterioration. In Chicago, two pollutants were measured: suspended particulate matter and SO_2. Because the latter was measured at only three of five exposure sites, however, statistical correlations could not be made. Nevertheless, plots of breaking strength versus mean SO_2 levels (Figure 2-4) showed an apparently strong relationship, but plots of suspended particulate matter were inconclusive.

Although the exposure studies of Brysson et al.[18] lacked the necessary requisites for a thorough statistical analysis, the results do show an apparent relationship between loss in strength of cotton fabrics and air pollution. Of the pollutants measured, SO_2 appears to be the one most responsible for causing damage.

Brysson et al.[19] also conducted laboratory studies in which they artificially treated samples of cotton print cloth with dilute concentrations of sulfuric or sulfurous acids and then exposed them to three controlled environments: 50 hours at room temperature (about 20°C) and darkness; 50 hours at 48°C and darkness; and 50 hours in a Fade-Ometer (carbon arc), in which the face temperature of the samples was 48°C. As can be seen from Figures 2-5 and 2-6, only the sulfuric acid caused degradation at the levels tested; apparently, low concentrations of sulfurous acid do not attack the cotton print cloth, nor do they convert appreciably to the higher oxidation state under the conditions of exposure. The data also show that artificial sunlight accelerates the degrading effect of sulfuric acid, and, according to the researchers, the degradation is greater than can be explained by the action of sunlight alone.

Later studies by Fye et al.[20] showed that, in the absence of artificial sunlight, cotton and rayon do not significantly deteriorate when they are continuously exposed for 90 days (under dynamic conditions) to a

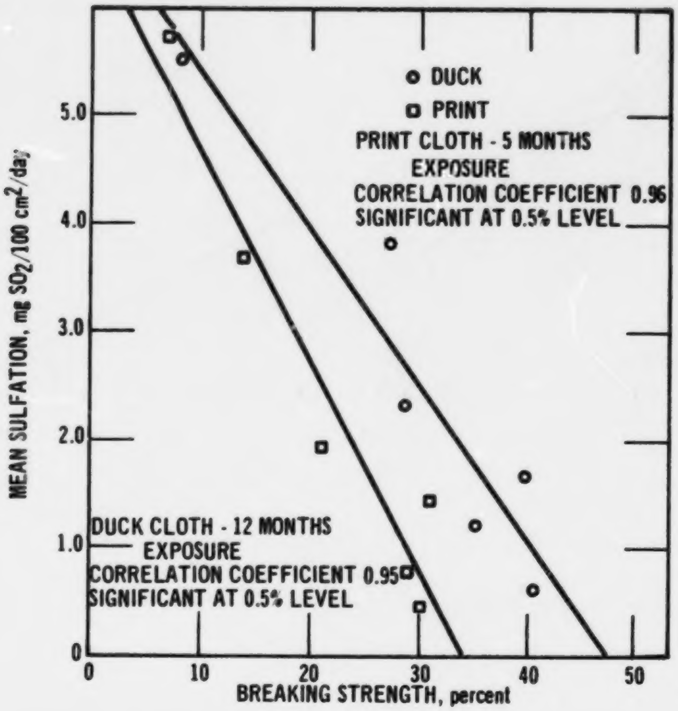

Figure 2-3. Relationship between retained breaking strength of cotton fabrics and corresponding mean sulfation rate measured at selected sites in St. Louis.

controlled environment containing 5350 $\mu g/m^3$ (2 ppm) SO_2 at 19°C and 75 percent relative humidity. The investigators concluded that lack of deterioration indicated that little or no SO_2 was converted to sulfuric acid, and that this result was probably attributable to the absence of sunlight during exposure.

In follow-up research, Long and Saville[21] continuously for 30 days in the absence of light, exposed cotton, acetate, and triacetate fabric specimens to air containing 5350 $\mu g/m^3$ (2 ppm) SO_2. Two controlled exposure conditions were used: 95 percent relative humidity at 33°C, and 90 percent relative humidity at 19°C. The investigators confirmed the presence of acid in the exposure chambers. Following exposure, breaking strength of half of the specimens was determined; the remaining specimens were tested after they had aged for an additional 30 days. As shown in Table 2-4, none of the fabrics showed pronounced deterioration despite the relatively severe exposure conditions. Acetate showed the most loss, about a 7 percent reduction in strength. The absence of light may have been a factor in the relative lack of deterioration.

Zeronian[22] carried out laboratory exposures that more closely approached actual service conditions. He exposed fabric samples of cotton (3.0 ounces per square yard), viscose rayon (4.2 oz/yd^2), and high-wet-modulus rayon (2.6 oz/yd^2) for 7 days to clean air (filtered through charcoal and soda lime) and to clean air containing 250 $\mu g/m^3$ (0.1 ppm) SO_2. Both environments included continuous exposure to artificial light (xenon arc) and a water spray turned on for 18 minutes every 2 hours. The dry bulb temperature was 40°C, and the relative humidity was maintained at 50 percent when the water spray was off. Under these controlled-environment conditions, loss in strength for all the fabrics exposed to clean air averaged 13 percent, while the fabrics exposed to air containing SO_2 averaged 21 percent.

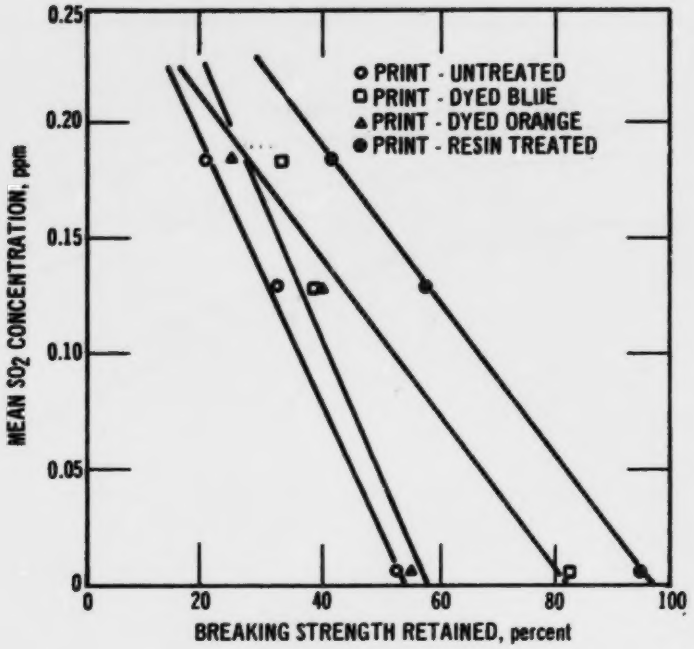

Figure 2-4. Relationship between retained breaking strength of cotton print cloth samples and mean sulfur dioxide concentration for 5-month exposure in three Chicago sites.

Table 2-4. MEAN BREAKING STRENGTH OF UNAGED FABRICS AND FABRICS AGED 30 DAYS FOLLOWING EXPOSURE TO A HUMID SULFUR DIOXIDE-POLLUTED ATMOSPHERE AT TWO TEMPERATURE LEVELS[a]

(pounds)

		High temperature, 33°C		Low temperature, 19°C	
Fiber	Control	Unaged	Aged	Unaged	Aged
Acetate	23.08	21.50	21.38	21.26	20.78
Triacetate	16.44	16.94	16.48	16.04	15.56
Cotton	35.78	35.32	33.52	33.76	36.42
Acrylic	45.18	43.45	44.80	40.94	43.60
Modacrylic	74.96	76.96	78.02	77.90	76.58
Nylon	114.72	110.16	111.20	110.64	111.82
Polyester	57.12	54.62	56.16	55.12	54.22

[a] SO_2 present at 2 ppm.

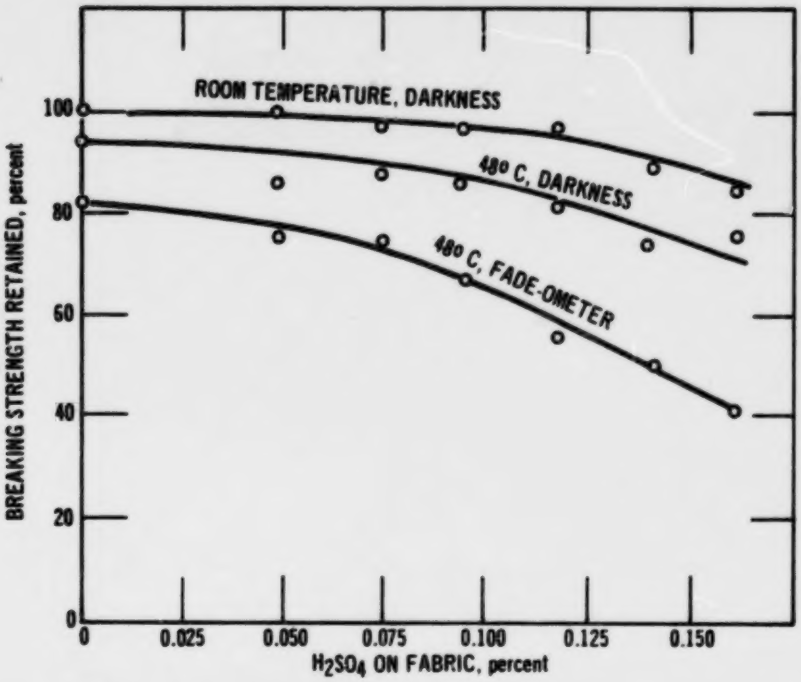

Figure 2-5. Breaking strength retained for sulfuric acid treated print cloth exposed for 50 hours at stated conditions.

Textile chemists do not agree on the mechanism by which cellulosic fabrics are degraded during atmospheric exposure. Some believe that all degradation is a process of oxidation by air and that the oxidation of airborne contaminants may set up chain reactions that accelerate the normal photochemical oxidation of cellulose by atmospheric oxygen; others attribute it to acid hydrolysis, which they claim causes various degrees of depolymerization in the fibers, resulting in lowered breaking strength. The remaining scientists take the view that degradation is a combination of both processes. Regardless of the mechanism, some air pollutants, especially SO_2, are important factors in causing the degradation of cellulosic textiles.

Effects on Synthetic Fibers and Blends

Research related to the effects of air contaminants on synthetic fibers has been limited, probably because of the notion that synthetic fibers are chemically stable. This presumption may be inaccurate, especially when possible synergistic effects are considered.

The first totally man-made fiber was nylon, a material possessing excellent resistance to most chemicals, though it is sensitive to strong acids. This sensitivity was vividly brought to light in 1941, 2 years after nylon hosiery was marketed, when an unprecedented outbreak of runs in women's stockings occurred in Washington, D. C. On investigating the problem, the National Bureau of Standards[23] interviewed the women who had worn the stockings and found that the numerous runs appeared suddenly, all at about the same time of day. The breaks responsible for these runs occurred predominately in the ankle and lower-leg areas. Tiny dark specks of matter could be seen with the unaided eye at most of the breaks. Microscopic examination showed that the broken fibers

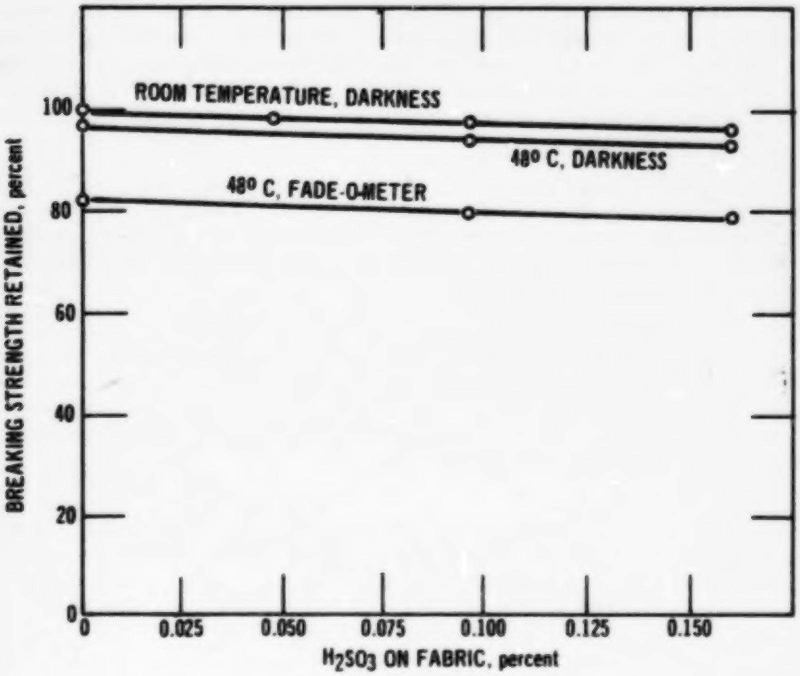

Figure 2-6. Breaking strength retained for sulfurous acid treated print cloth exposed for 50 hours at stated conditions.

clearly had been acted on by a chemical at the point of rupture and that they showed no sign of having been severed by cutting or abrasion. Furthermore, chemical tests showed the fibers to be strongly acidic in the vicinity of the particles and breaks, but nowhere else. The acid was identified as sulfuric acid. Runs were attributed to the action of acid sorbed by airborne particles that deposited on the stockings. DuPont[24] conducted additional studies and found that outbreaks of runs were caused by a combination of adverse factors: high air-pollution levels, high humidity, and, in many instances, poor air circulation. The source of the sulfuric acid was generally attributed to atmospheric SO_2.

Nylon stockings are especially sensitive because they are ultrasheer, are knitted rather than woven, and are under constant tension when worn so that the slightest break in threads may start runs. On the other hand, woven nylon fabrics used in such clothing items as blouses and shirts are not sheer and are comparatively free from stress; thus, they are not so easily damaged by acid pollutants.

Although Washington, D. C., was the scene of the first outbreak of runs in nylon stockings, other cities also have experienced incidents. New York, Chicago, Los Angeles, Jacksonville, and Nashville, for example, have reported such outbreaks.[24] Similar incidents have occurred in foreign countries.[25,26] Frequently, outbreaks take place in localized areas such as in the vicinity of chemical plants or railroad stations. Many incidents go unreported, however, because they are not concentrated in a single area, and women tend to place the blame on hosiery manufacturers.[27]

Travnicek[25] investigated the effects of air pollution on synthetic fibers by conducting laboratory studies in exposure chambers. He confirmed that damage occurs to nylon fibers from SO_2-laden soot by exposing nylon fibers to activated charcoal saturated with SO_2. He found that this artificial soot must usually be activated by heat or light in the presence of high humidity to produce damage. He also observed that damage to more acid-resistant fibers (polyesters, polyolefins) was less pronounced, but that a distinct weakening did occur under these conditions. Unfortunately, it is impossible to assess this research fully because Travnicek did not delineate his methodology or quantitatively define the exposure conditions and results.

Fye et al.[20] continuously exposed polyester, 65/35 polyester-cotton blend, and nylon fabrics to a controlled environment (dynamic conditions) containing 5350 $\mu g/m^3$ (2 ppm) SO_2 at 19°C and 75 percent relative humidity for 90 days in the absence of light. Only nylon showed a significant loss in breaking strength, and the loss was small—less than 5 percent. The investigators concluded that SO_2 itself had a direct deleterious effect on the nylon and that little or no SO_2 was converted to sulfuric acid.

The study of Long and Saville[21] followed up Fye's work. They exposed acrylic, modacrylic, nylon, and polyester fabric specimens to the conditions previously described. As Table 2-4 shows, acrylic, nylon, and polyester fibers decreased slightly in strength, while the strength of the modacrylic specimens increased a small amount. Therefore, none of the fibers showed pronounced damage despite the severity of the exposure conditions. The absence of artificial sunlight may have been a factor.

In recently completed laboratory research, Zeronian et al.[28] simultaneously exposed modacrylic (Dynel), nylon 66, and polyester (Dacron) fabrics to artificial sunlight (xenon arc) and charcoal-filtered clean air contaminated with 486 $\mu g/m^3$ (0.2 ppm) SO_2. The fabric samples were also automatically sprayed with water for 18 minutes every 2 hours during exposure. During the "light only" part of the cycle, the exposure temperature was 48°C and the relative humidity 39 percent. To separate the damage that SO_2 may cause from the detrimental effects of artificial sunlight, fabric samples were also exposed to the same controlled environmental conditions, except that the clean air was not contaminated with SO_2. Loss in fiber strength was the prime measure used to assess degradation.

After exposure for 7 days to these controlled environments, Zeronian et al. found that SO_2 did not affect the modacrylic and polyester fabrics, but did significantly accelerate the degradation of nylon. The nylon fabrics exposed to SO_2 lost 80 percent of their strength, while the fabrics exposed to uncontaminated air lost 40 percent of their strength. The exposure results also show that SO_2 can degrade nylon in the absence of particulate matter. By means of other physical and chemical tests, the investigators further concluded that, under these exposure conditions, degradation was not caused by acid hydrolysis resulting from the conversion of SO_2 to sulfuric acid. Sufficient chemical evidence, however, was not collected in this study to permit elucidation of the mechanism of the photodegradation of nylon in the presence of SO_2. The investigators pointed out that the nylon used in this study was a commercial grade containing a delustrant. Since delustrants accelerate the photooxidation of nylon, further research is needed to establish whether delustrants influence reactions between SO_2 and nylon.

Zeronian[29] also examined the surfaces of exposed nylon fibers under a scanning electron microscope. He observed that the surfaces of fibers exposed for 7 days to light (xenon arc) and clean air, plus intermittent water spraying, developed a small number of scattered minute pits. Under similar exposure conditions but with the clean air contaminated with 486 $\mu g/m^3$ (0.2 ppm) SO_2, however, the nylon surfaces developed numerous large cavities; on some fibers, finely etched lines were also present. A similar appearance was also found on fibers exposed for 14 days to light and clean air (no SO_2) with intermittent water spraying, although loss in tensile strength (70 percent) was less than the loss (80 percent) found when SO_2 was present. Apparently, SO_2 accelerates degradation under these exposure conditions, but does not alter the manner in which degradation takes place. Zeronian also observed that cavities and pits seem to develop only when intermittent water spraying is a part of the exposure conditions. The surfaces of nylon fibers remained smooth when the samples were exposed for 7 days to light and air (49°C and 38 percent relative humidity) contaminated with 486 $\mu g/m^3$ (0.2 ppm) SO_2, but without periodic water spraying. Loss in strength was 50 percent under these conditions. Additional research is necessary to assess the significance of the surface imperfections observed in these experiments.

NITROGEN OXIDES

Nitrogen oxides (NO_x) are prime components of photochemical smog. Among the nitrogen oxides, nitric oxide (NO) and nitrogen dioxide (NO_2) are the most important as pollutants. Nitric oxide is the main product formed during high-temperature combustion processes when atmospheric oxygen and nitrogen combine. Although some NO_2 is also produced during these processes, most of the NO_2 found in ambient air is formed by the oxidation of NO. The presence of sunlight and hydrocarbons in the atmosphere accelerates this oxidation reaction enormously. The main sources of NO_x emissions to the atmosphere are automobiles and power plants.

Effects on Natural Fibers

Researchers have not studied the direct effects of NO_x on cellulosic fibers, but Morris et al.[30] conducted a field investigation in Berkeley, California, in which they attributed the observed fiber damage to ambient levels of NO_x. They exposed samples of combed cotton yarn at a 45-degree angle in cabinets facing south. Polyvinyl fluoride film, rather than glass, was used to cover the cabinets in order to allow a greater amount of sunlight to enter. One cabinet was set up as a control unit in which entering air was filtered through carbon canisters; ambient air was circulated through the other cabinet. (The investigators did not note the rate of air change.) In each cabinet some samples were exposed directly to daylight, while like samples were shaded. Samples were exposed for three separate 28-day periods (December through February), as well as for consecutive combinations of these three periods (Table 2-5). During exposure, air pollution and weather measurements were made as shown in Table 2-6.

At least 20 yarn specimens were evaluated for each exposure period. The investigators assessed deterioration by measuring loss in breaking strength. Table 2-5 shows, for the various exposure periods, mean values for the percentage loss in breaking strength for unshaded samples exposed to filtered and unfiltered ambient air. An analysis of variance of these mean loss values revealed that unfiltered air deteriorates cotton yarn to a significantly greater extent than filtered air. No difference was observed, however, in the effects of filtered and unfiltered air on the shaded samples. Although textile investigators have been aware of the pronounced deteriorating action of direct sunlight, the results of this study emphasize the importance of sunlight in stimulating reactions between some air pollutants and materials. It is noteworthy that the smallest difference in breaking-strength losses between filtered and unfiltered air occurred during February, which is the period having the most rain (which cleans the air), the lowest levels of NO_x, and the lowest total hours of sunshine. Although they found it impossible to determine the responsible pollutant in this study, the investigators proposed that nitrogen oxides, either directly or indirectly, were instrumental in causing damage. Sulfur dioxide was not measured because levels were known to be low.

The investigators did not mention the fact that the filter material, activated carbon, adsorbs NO_2 effectively but adsorbs NO poorly. Levels of NO in the filtered air cabinet could, conceivably, have contributed to the decrease in breaking strength. If this were the case, cotton specimens exposed to clean air would show a smaller loss in breaking strength, and the relative pollution effect would increase.

Effects on Synthetic Fibers and Blends

Several investigators, working with synthetic fibers, have found that under laboratory conditions nitrogen oxides are capable of causing damage. They reason, therefore, that these pollutants are potential threats under ambient conditions. Damage reports from the field, however, have been few, and only one incident has been documented.

In March 1964, an episode of runs in nylon stockings worn by women occurred in the vicinity of a demolition project in downtown New York City.[31] Investigators identified the agent causing the damage as NO_2 gas released during dynamite blasting operations. Local weather conditions at that time were unfavorable in that a temperature inversion existed along with wind stagnation and high humidity. The investigators proposed that the combination of these conditions in the presence of abnormally high levels of released NO_2 and dust had produced nitric acid aerosols that damaged the nylon stockings.

Table 2-5. BREAKING STRENGTH OF COTTON YARN SAMPLES EXPOSED TO AIR AND SUNLIGHT IN BERKELEY, CALIFORNIA

Exposure		Breaking strength lost, %	
Number of days	Period	Filtered air	Unfiltered air
28	Dec.	11	15
28	Jan.	15	18
28	Feb.	15	16
56	Dec. - Jan.	20	24
56	Jan. - Feb.	19	29
84	Dec. - Feb.	26	32

Table 2-6. AIR POLLUTANT LEVELS[a] AND WEATHER MEASUREMENTS

Exposure period	Total oxidant		Nitric oxide		Nitrogen dioxide		Temp., °C	Total sunshine, % days	Rain, in.
	ppm	μg/m³	ppm	μg/m³	ppm	μg/m³			
Dec.	0.03	60	0.19	230	0.08	150	10	100	0.5
Jan.	0.03	60	0.23	280	0.08	150	10	100	6
Feb.	0.03	60	0.07	90	0.05	90	10	72	10

[a] For clock hour with highest average value.

Travnicek[25] gathered information on incidents involving air pollution damage to nylon stockings and, noting the New York City episode, offered the opinion that "the corrosive effect of nitrogen oxides is rather high not only for nylons but for practically all other fiber-forming polymers because it combines acid corrosion and oxidation."

Because nitrogen oxides are major components of auto exhaust, the laboratory research that Travnicek[25] carried out may be significant. He exposed samples of synthetic fibers (only nylon is identified) for 50 hours to a continuous flow of undiluted auto exhaust in a controlled-environment chamber illuminated by artificial sunlight. Travnicek found that under these exposure conditions, the physical properties of the fibers changed, and that the changes were caused by the interplay of two reactions: cross-linking, probably the result of aldehydes; and depolymerization, caused largely by light. Furthermore, he observed that, to a certain degree, some light stabilizers and dyes, because of preferential reactions with oxidizing agents, protected the fibers from degradation. Protection is most evident when NO_x and sunlight transform components of exhaust gases into oxidizing agents. When fibers were exposed to dilute exhaust gases, which simulated summertime conditions on traffic-congested streets, Travnicek found that the diluted gases became a potential menace to these fibers only if given sufficient time and light to produce oxidizing substances. He did not define "sufficient time and light." According to Travnicek, therefore, NO_x may attack and damage fibers through the formation of nitric acid droplets, by direct oxidation, and by conversion of other exhaust components into harmful oxidizing agents. Unfortunately, Travnicek discusses generalities and does not present a detailed account of his methodology and results.

Nitrogen oxides may pose a problem for Spandex, a synthetic elastomeric fiber. On exposure to a standard laboratory test procedure in which levels of NO_2 were about 2500 $\mu g/m^3$ (1.5 ppm), Spandex developed a yellowish discoloration.[32] This result is not a case of dye fading since the exposed material contained no dyes or color pigments; rather, the NO_x react directly with the polymer. Although the laboratory test exposure levels are somewhat higher than measured levels in ambient air, problems may develop under ambient conditions. So far, however, few complaints from the field have been registered.

Citing recent technology on the dyeing of DuPont nylon yarns, Trommer[33] states that nylon polymers are subject to oxidation by NO_x and other oxidants, and may themselves serve as reducing agents. If oxidation occurs, nylon fibers then have less affinity for acid dyes. Natural (undyed) continuous-filament styling yarns, which have a high capacity for acid dyes, are especially sensitive to oxidation reactions. Trommer cautions that these nylon yarns should not be exposed for prolonged periods to factory environments in which fork trucks emit exhaust fumes.

In laboratory research that Zeronian et al.[28] completed in 1971, fabric samples of modacrylic (Dynel), acrylic (Orlon), nylon 66, and polyester (Dacron) were simultaneously exposed to artificial light (xenon arc) and charcoal-filtered clean air contaminated with 350 $\mu g/m^3$ (0.2 ppm) NO_2 at 48°C and 39 percent relative humidity. During exposure, the fabric samples were sprayed with water for 18 minutes every 2 hours. Damage by NO_2 was measured by comparison with fabrics exposed to the same environmental conditions but without NO_2. When they exposed the fabrics to these controlled conditions for 7 days, Zeronian et al. found that NO_2 did not affect the modacrylic fabrics, but appeared to affect the other fabrics slightly. The evidence for damage to nylon appeared to be the strongest, although the investigators emphasize that the results for all fabrics were not clear and that more research is needed.

OZONE

Ozone occurs naturally in the atmosphere; however, undesirable concentrations of ozone often occur as a result of complex photochemical reactions between NO_2 and hydrocarbons. Thus, ozone is a principal component of photochemical smog and is primarily an indirect product of automobile emissions.

Effects on Natrual Fibers

Because cellulose fibers are vulnerable to oxidation, ambient levels of atmospheric ozone, a powerful oxidizing agent, are a potential cause of degradation. With this in mind, Bogaty et al.[34] conducted laboratory experiments to study the possible role of ozone in the deterioration of cotton products. They exposed samples of duck and print cloth to air containing between 40 and 120 $\mu g/m^3$ (0.02 and 0.06 ppm) ozone at room temperature and in the absence of light. Samples were exposed both dry and wet; the moisture content of the wet samples was never less than 50 percent.

After exposure for 50 days, fluidity values increased for the cotton samples that were moist during exposure, but did not appreciably change for the samples that remained dry during exposure. Fluidity values for control samples that were kept moist but not exposed to ozone showed little change. These results indicated that ozone caused virtually all the degradation. In addition to changes in fluidity, the moist samples showed a 20 percent loss in tensile strength after exposure to ozone. Similar fabrics were also exposed to higher levels of ozone, resulting in a greater increase in the degradation (fluidity) of the moist samples. The overall study showed that low levels of ozone degrade cotton fabrics if the fabrics are sufficiently moist. The mechanism of ozone attack appears primarily to be solubilization in water, since at room temperature ozone is considerably more soluble in water than it is in air.

The investigators estimated that the laboratory exposure conditions (50 days, high moisture, and ozone) are equivalent to 500 days of exposure under field conditions. They concluded that ambient levels of ozone, while capable of damaging moist cotton fabrics, produces deterioration that is slight in comparison with that from other elements of weathering such as light, heat, alternate wetting and drying, and micro-organisms.

Morris[35] also studied the effect of ozone on cotton. Samples of special print cloth were exposed in the absence of light to 995 $\mu g/m^3$ (0.5 ppm) ozone for 50 days in a chamber maintained at 21°C and 72 percent relative humidity. No appreciable effect on breaking strength or fluidity was found. Apparently the moisture content of the cotton (9 percent) was not high enough to produce the degradation that Bogaty measured on wet cotton samples, even though the concentration of ozone was considerably higher (about 10 times).

In a recent laboratory study, Kerr et al.[36] examined the effect of periodic washing on the tendering of cotton fabrics exposed to ozone. They exposed samples of print cloth, dyed with C. I. Vat Blue 29, in a chamber to a continuous supply of clean air contaminated with ozone. The concentration of ozone averaged 1470 $\mu g/m^3$ (0.75 ppm), and samples were exposed at room temperature in the absence of light. The investigators did not measure relative humidity, although they attempted to increase the humidity by placing a pan of water on the chamber floor. At 3-day intervals the cotton samples were removed from the chamber. Half of them were machine-washed and the other half were soaked in water for 1 minute. All samples were passed through a hand wringer to remove excess water before being returned to the chamber for further exposure. Control samples were kept in a light-tight box maintained at 21°C and 65 percent relative humidity and were given the same washing and soaking treatment.

After the samples were exposed for 60 days, which included 20 washing or soaking treatments, the change in strength for the control fabrics was measured and found to be insignificant. By comparison the fabrics exposed to ozone changed significantly; the loss in strength for the washed fabrics was 18 percent and for the soaked fabrics 9 percent. The investigators attributed these losses to ozone.

Since Morris[35] found no degradation under exposure conditions similar to those used by Kerr, the washing and soaking treatment would appear to affect in some way the sensitivity of the fabrics to ozone. Nevertheless, if one attempts to equate Kerr's findings with "real world" conditions, the degradation appears minimal in view of the fact that average levels of ozone under field conditions are less than 10 percent of the levels used in the laboratory exposure.

Effects on Synthetic Fibers and Blends

Despite the strong oxidizing power of atmospheric ozone, little research has been carried out on the effects of this pollutant on synthetic fibers. Peters and Saville,[37] however, did study the combined damaging effects of high levels of ozone and ultraviolet light on the breaking strength of white curtain marquisettes made of nylon, polyester, cotton, acetate, and fiber glass. They exposed samples of these fabrics in a chamber under conditions that were not tightly controlled. Ozone generators located inside the chamber were adjusted to produce a level of ozone sufficient to fade an ozone-sensitive acetate test ribbon during a 9-day exposure period an amount equivalent to Step 2 on the International Geometric Gray Scale. The investigators made no estimates of the levels of ozone produced under these conditions except to say that they were high. During exposure, the temperature averaged 31°C and the relative humidity averaged 68 percent. The intensity of the ultraviolet light was not measured.

The investigators found that, after exposure under these conditions for 45 days, the loss in breaking strength for nylon averaged 64 percent, for polyester 18 percent, for acetate 15 percent, for cotton 12 percent, and for fiber glass 7 percent. Because no control fabrics were exposed under similar conditions but in the absence of ozone, it is impossible to establish the damage contribution by ozone, if any. This factor is especially significant since ultraviolet light is considered the prime environmental source of fiber degradation.

In more sophisticated laboratory studies, Zeronian et al.[28] simultaneously exposed modacrylic (Dynel), acrylic (Orlon), nylon 66, and polyester (Dacron) fabrics to artificial sunlight (xenon arc) and charcoal-filtered clean air contaminated with 365 $\mu g/m^3$ (0.2 ppm) ozone at 48°C and 39 percent relative humidity. During exposure, the fabric samples were sprayed with water for 18 minutes every 2 hours. Ozone damage was measured by comparison with fabrics exposed to the same environmental conditions but without ozone. After exposure for 7 days, Zeronian et al. found that ozone did not affect the modacrylic and polyester fibers, but seemed to affect the acrylic and nylon fibers slightly.

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CHAPTER 3

EFFECTS OF AIR POLLUTANTS ON TEXTILE DYES AND ADDITIVES

Although sunlight is the major cause of color defects in dyed textile fabrics, air pollutants, to the dismay of the textile industry, are also important factors in causing color defects. Just as dyes vary in their sensitivity to sunlight, so do they vary in their sensitivity to individual pollutants. With sunlight, the more sensitive dye molecules become activated and unstable as they absorb actinic energy. This instability is short-lived, however, and the dye molecules usually break down, normally by oxidation but sometimes by reduction, resulting in a change or loss in color. Pollutants react directly with sensitive dyes to produce different compounds and colors. In many cases, environmental factors such as relative humidity and sunlight play major roles by accelerating the rates of chemical reaction. Closely related to color change problems induced by air pollution are the effects of pollutants on textile additives, which are widely used to enhance certain properties of fabrics and dyes. Additives include light stabilizers, permanent-press resins, optical brighteners, antistatic and soil-release finishers, softeners, and various inhibitors.

SULFUR OXIDES

Potential Problem

Although the textile industry has reported many incidents of dyed fabrics developing color defects, none have been attributed to ambient levels of atmospheric SO_2. However, because SO_2 and solutions of its reaction produce with water–sulfurous acid–are active reducing agents and are used to bleach wool and silk, dye chemists have recognized for some time that atmospheric SO_2 could be potentially troublesome. They are also aware that portions of dyed fabrics have faded when placed in direct contact with paper or other fiber products manufactured from sulfite pulp; frequently these paper products contain residual SO_2.[1] In addition, many dyes are basic compounds, and some, especially those developed and used many years ago, are sensitive to acid-base changes. Color changes resulting from such sensitivity are called acid fading. The original color shade of dyes susceptible to acid fading can be easily restored by the application of ammonia or other mild alkali.[2] Although airborne acid aerosols derived from SO_2 (sulfurous and sulfuric acids) could cause acid fading, such fading is no longer a common problem because present-day dyehouse processing operations include exposure of dyed fabrics to dilute mineral acids; as a consequence, acid-susceptible dyes cannot be used.

Early Laboratory Investigations

The lack of evidence against fading by atmospheric SO_2 has not lulled researchers into a "do-nothing" attitude. During the late 1920's and the 1930's, several laboratory studies were conducted to assess the effects of SO_2-contaminated air on dyes. In most exposures, SO_2 was chemically generated and concentrations were not measured. Scientists generally assumed, however, that concentrations were considerably higher than those that normally exist in industrial environments.

Cunliffe[3] subjected a number of dyes on cotton, viscose rayon, linen, silk, and wool to SO_2-contaminated air, both in the presence and absence of artificial light. He found that in the presence of light SO_2 decreased the fading rate of sulfur dyes on cotton, rayon, and linen, and of azo dyes on cotton. Sulfur dioxide either increased or decreased the fading rates of the remaining dyes on the cellulosic fabrics and of all dyes on wool and silk. For a number of dyes, changes in hue also were noted in addition to fading. In the exposures conducted in darkness, SO_2 affected the majority of the dyes on all fibers; dyes on cotton showed the greatest variety of change. Since SO_2 concentrations were not stated, however, it is not possible to assess completely the significance of these results.

Prior to the late 1920's, dye chemists thought that if SO_2 caused color defects, it would be either by bleaching or by an acid-base reaction. The research of King[1,4] and Goodall[5] brought to light another mechanism by which SO_2 can cause dyes to fade. They showed that, because fabrics are usually slightly alkaline as a result of residues remaining from previous processing and laundering operations, SO_2, in the presence of moisture, can react with the alkali to form bisulfites and alkali sulfites. These sulfites can cause color defects by reacting with sensitive dyes to form addition compounds or by completely reducing the dyes. The addition reaction is more common and certain azo dyes on wool are especially sensitive. The researchers found that optimum conditions for the formation of azo-sulfite addition compounds occur when the pH is slightly acid (6.8 to 6.9) and the concentration of alkali is from 1.25 to 1.4 times that of SO_2. Conceivably, these optimum conditions could be met by ambient levels of SO_2-contaminated air. The reduction reaction is comparatively slow and optimum conditions vary with each dye. Although sulfite-induced color defects in dyed fabrics are easily produced in the laboratory, none have been observed in service.

Subsequent laboratory studies revealed that certain dyed fabrics were reasonably resistant to color changes when exposed to SO_2-contaminated air. Jones[6] subjected dyed cotton fabrics (nine vat dyes) and viscose rayon fabrics (nine vat dyes, four direct dyes, and one sulfur dye) to dry air containing about 3000 ppm SO_2 and to moist air (humidity not given) containing about 3000 ppm SO_2. Both exposures, each lasting 41 days, were conducted at room temperature and under glass, to allow natural sunlight to fall on the fabric samples. No dyed fabrics faded when exposed to the dry-air-conditions. Under the moist-air conditions, one vat-dyed cotton fabric showed obvious fading and two others showed slight fading; no rayon fabrics faded.

Rowe and Chamberlain[7] found that gaseous SO_2 had little effect when passed into aqueous suspensions of basic dyes (anthraquinonid family) for acetate rayon. When SO_2 and NO_x were simultaneously passed into aqueous suspensions of these dyes, SO_2 appeared to modify the pronounced fading action of NO_x. On the basis of these severe tests, the investigators concluded that ambient levels of SO_2, though still capable of causing acid fading, should not directly fade these dyes.

Laboratory investigations carried out in the late 1940's likewise showed a negative effect for SO_2-contaminated air.[8] No visible color changes developed on several dyed viscose and acetate rayon fabrics when they were exposed for 2 hours to air containing about 320 ppm SO_2 at 65°C and 50 percent relative humidity. Neither did exposures conducted at lower temperatures and humidities produce color defects.

AATCC Laboratory and Field Exposures

During the 1950's, investigators conducting lightfastness tests (measuring resistance to fading by sunlight) found that significant differences in lightfastness occurred among some dyed fabrics when they were exposed outdoors to equivalent amounts of sunlight but at different localities. The investigators reasoned that one of the variables responsible for this result was contaminated air. To explore this variable in greater detail, the American Association of Textile Chemists and Colorists (AATCC) set up a committee to carry out laboratory research and field studies.

Although the ensuing laboratory research[9] did not include an investigation of the direct effects of SO_2, it did include a study of the effects of dilute sulfuric acid. The committee selected 28 dyed fabrics consisting of cellulosic (cotton and viscose rayon), nylon, and wool fibers, all dyed with conventional dyes. Each fabric was treated with a weak solution of sulfuric acid (1 gram per liter) at 40°C for 20 minutes followed by a water rinse at 30°C for 5 minutes. After this treatment, the fabrics were inspected for color change. They were then exposed in a Fade-Ometer for up to 40 hours to evaluate lightfastness. The acid treatment produced no color defects on the dyed nylon and wool fabrics, but several direct dyes on cellulosic fabrics developed moderate acid-base color changes. More importantly, however, these direct-dyed cellulosic fabrics that had been acid-treated suffered appreciable reduction in lightfastness. The AATCC concluded that, during sunlight testing in various geographic locations, the action of absorbed acid pollutants on dyed cellulosic fabrics may contribute to observed differences in lightfastness.

Subsequently, the AATCC Committee conducted service exposure trials in urban and rural areas.[10-12] Fifty-two dyed samples were exposed for 90 days (October-December 1961) at sites in Phoenix, Arizona; Sarasota, Florida; Los Angeles, California; and Chicago, Illinois. Relative levels of atmospheric contaminants were reasonably well-known at the sites chosen. The dyed samples covered a range of fibers: cellulosics, acetate rayon, wool, nylon, acrylic, and polyester. The investigators selected dyes that were in common use on each fiber. The fabric samples were mounted inside exposure cabinets designed to allow free interchange of outside air but to exclude light.

Results showed that the atmosphere of Chicago produced a number of fading effects not observed at the other sites. Direct dyes and some reactive dyes on cellulosic fibers and acid dyes on wool and nylon developed pronounced color defects. Because high levels of SO_2 were frequently observed in Chicago, SO_2 or its acid derivatives were suggested as important factors. Some researchers suspected that the color defects observed on the cellulosic fabrics were produced by ambient levels of NO_x, which were also reasonably high in Chicago. The fading reaction of NO_x is markedly accelerated under acid conditions.

Recent Investigations

The service exposure trials were followed up by a more comprehensive field study conducted by air pollution researchers with the Environmental Protection Agency in cooperation with the AATCC.[13] The investigators selected 67 dye-fabric combinations for testing; the fibers from which the fabrics were woven included the cellulosics (cotton and viscose rayon), acetate rayon, wool, nylon, polyester, and acrylic. The dyes were mainly those commonly used on these fibers and represented various degrees of known susceptibility to air pollution fading. Fabric samples were exposed in light-tight cabinets similar to those used in the service trials. Individual cabinets were set up at 11 nationwide exposure sites: Los Angeles, California; Tacoma, Washington; Chicago, Illinois; Washington, D.C., and at corresponding rural control sites for each of these cities; additional single sites were located in Cincinnati, Ohio; Phoenix, Arizona; and Sarasota, Florida. These sites represented a cross section of various types of pollution and climates. Air pollutants were continuously measured near the urban sites in Chicago, Cincinnati, Los Angeles, and Washington. The study, conducted over a 2-year period, consisted of eight consecutive seasonal exposures, lasting 3 months each and commencing with the spring season (March-May 1966). Using a precision photoelectric colorimeter to measure color before and after exposure, the researchers calculated color changes for all dyed fabric samples at all sites for all seasonal exposures.

In an effort to identify factors causing fading in this study, the investigators statistically analyzed color change data, along with air pollution and weather measurements. Of the 67 fabrics exposed, 24 either did not fade or faded only a trace, and therefore were eliminated from statistical consideration; the remaining 43 fabrics faded in appreciable amounts. Most of these fabrics faded significantly more at urban sites than at corresponding rural sites, and the amount of fading varied between metropolitan areas and among seasons. Air pollution was assumed to account for most of the environmental differences between urban and rural sites.

Of the pollutants measured in this study, SO_2, NO_2, and ozone (O_3) seemed, on further analysis, to be most responsible for the fading of the fabrics. Temperature and humidity appear to have little influence on fading when dyed fabrics are exposed in essentially pollution-free environments. In polluted environments, however, high temperature and humidity may accelerate fading. Sulfur dioxide was a significant variable in the fading of 23 of the dyed fabrics. Furthermore, these fabrics faded only in Chicago, when SO_2 levels were high (fall and winter seasons). The apparent dominance of SO_2, however, should be qualified. High levels of SO_2 occurred only in Chicago; therefore, at no other exposure site could the researchers verify the fading measured in Chicago. In addition, despite measures taken to minimize it during exposure, soiling occurred and was particularly noticeable in Chicago. As a result, soiling confounded the statistical analyses.

Also of interest in this study is the fact that 45 of the 67 fabrics exposed experienced maximum fading in Chicago during at least one season. The most severe cases were the acid-dyed woolen fabrics. Many of the fabrics, however, showed considerably less fading than that observed on the woolens. Some of the fabrics that faded in Chicago are even considered to be generally resistant to fading by all air pollutants. Here again, soiling may have contributed to observed changes in color, especially for the pastel shades.

Also as part of this investigation, these same dye-fabric combinations were exposed, in the absence of light, to various combinations of dilute auto exhaust and SO_2.[14] Each fabric was exposed to clean air for 6 days, with the pollutants added for 9 hours each day. Auto exhaust alone produced no fading, nor did clean air plus 2620 $\mu g/m^3$ (1 ppm) SO_2. Irradiated auto exhaust, however, caused significant fading in some dyes; and irradiated exhaust plus 2620 $\mu g/m^3$ (1 ppm) SO_2 produced fading in additional dyes, as well as more pronounced fading in those dyed that faded without SO_2. These results illustrate the positive synergistic effect of SO_2 and auto exhaust, emphasizing that in many cases damage is a function of pollutants working together rather than by themselves.

Beloin[15] conducted laboratory studies that were designed to assess directly the effects of individual pollutants on dyed fabrics. He exposed 20 dye-fabric combinations for 12 consecutive weeks in the absence of light to individually controlled environments consisting of charcoal-filtered clean air (controls) and clean air contaminated with single pollutants. The pollutants were SO_2, NO, NO_2, and ozone (O_3). Controlled exposure conditions included clean air and two pollution levels, 260 $\mu g/m^3$ (0.1 ppm) SO_2 and 2600 $\mu g/m^3$ (1.0 ppm) SO_2, all under four combinations of temperature and relative humidity (RH): 32°C, 50 percent RH; 32°C, 90 percent RH; 13°C, 50 percent RH; and 13°C, 90 percent RH. The 20 fabrics selected were a cross section of those that showed the greatest tendency to fade during the field study[13] previously described, together with several nonfaders that served as controls.

Exposure results showed that SO_2 caused some cotton, nylon, and wool fabrics to fade. For the cotton and nylon fabrics, however, the fading effect of other pollutants was much stronger than that of SO_2. This was not the case for the wool fabrics; SO_2 was the only pollutant to cause visible fading. Relative humidity was a significant factor in accelerating the fading action of SO_2 on these wool fabrics, especially during exposure to the higher SO_2 concentration. The magnitude of fading measured on the wool fabrics after exposure to the most severe SO_2 controlled environments, however, was considerably less than the magnitude of fading that many of the other fabrics developed during exposure to NO_2 or O_3.

Despite the fact that service complaints concerning color defects on textile fabrics have not been attributed to SO_2-contaminated air (although suspected in some cases), researchers believe that the potential is still real. Presently, both the AATCC and European groups are developing test procedures to assess colorfastness to SO_2-contaminated air.

NITROGEN OXIDES

Discovery of "Gas Fading"

The fading effects of NO_x have been a problem for the textile industry for many decades. Evidence first appeared in Germany just prior to World War I when a dye manufacturer investigated some unusual cases of dye fading on stored wool goods.[16] Fading was most noticeable on the edges of the goods, and the primary cause was traced to NO_x in the air. Open electric-arc lamps and incandescent gas mantles were major sources of these pollutants, which were produced by high-temperature fixation of nitrogen in the air. The investigators found that all the susceptible dyes contained free or substituted amino groups, which they suggested might become either diazotized or nitrosated by the NO_x.

During and following World War I, increased replacement of older forms of lighting with electric filament lamps led to a general decline of the wool-fading problem. In the mid-1920's, however, researchers developed and introduced a new fiber, cellulose acetate rayon, and, since traditional dyes were of little use on the new material, chemists soon developed an entirely new line of dyestuff called disperse dyes. These dyes are slightly soluble in water and color acetate fibers by a mechanism of solid solution. Many are derived from anthraquinone and therefore contain amino groups, the same groups the Germans had previously found susceptible to NO_x fading. Anthraquinone dyes are basic compounds; basicity is necessary for adequate dyeing affinity.

Shortly after the introduction of disperse-dyed acetate fabrics, a puzzling type of fading began to show up more and more. Fading occurred mainly on blue and violet shades, with both colors developing a pronounced reddening. Because this fading was frequently observed in rooms heated by gas heaters, it was called "gas-fume fading" or "gas fading," and was confined to disperse dyes on cellulose acetate rayon.

During the 1930's acetate fading became a serious problem as an increasing number of fading incidents came to the attention of the textile industry. These incidents occurred during manufacturing and storage, product display by retailers, drying and ironing of laundered garments, and storage by consumers.[2,6] Apparently unaware of the earlier German work, dye and fiber chemists devoted considerable efforts toward finding a solution. These efforts culminated in 1937 when Rowe and Chamberlain[7] systematically investigated the fundamental chemistry of dye degradation. They independently reached the same conclusions as the earlier German team—that NO_x were the active agents in combusted gas that caused a number of dyes on acetate fabrics to fade permanently. The investigators also found that these same dyes, when applied to wool rather than acetate fabrics, showed little fading on exposure to combusted gas, contrary to the German observations. Rowe and Chamberlain concluded that wool absorbs NO_x thus protecting the dyes from attack. In the German research, the woolen goods may have reached their maximum ability to absorb NO_x, so that the NO_x was then available to react with the sensitive dyes.

By the late 1930's, gas-sensitive dyes on acetate rayon fabrics covered about one-half the color spectrum.[17] Dyes covering the other half, including most of the yellows, oranges, and reds, consisted largely of azo compounds and were reasonably resistant. Mod shades, which require several component dyes including the sensitive blues, are also subject to gas fading.

Standard Test Method

Recognizing the importance of the problem, the AATCC Committee on Colorfastness to Atmospheric Contaminants, supplemented by outside research,[8,18-22] developed a fading test procedure that the members tentatively adopted in 1941 and formally approved in 1957. It is presently designated as Test Method 23-1972, Colorfastness to Burnt Gas Fumes.[23] This method calls for suspending test specimens, along with gas-fading control samples (AATCC Control Sample No. 1), in a chamber and exposing them to combustion gases from a gas burner that has been adjusted so that the chamber temperature does not exceed 60°C. The resulting concentration of NO_2 is about 2.5 milligrams per cubic meter (mg/m^3) (1.5 ppm). Relative humidity is not measured or controlled, but depends on the moisture content of the air at the time of testing. The control sample, frequently called the gas-fading control ribbon, is a satin cellulose acetate fabric dyed with 1 percent C. I. Disperse Blue 3, a sensitive anthraquinone dye. Specimens remain in the chamber until the control sample shows a change in shade (duller and redder) corresponding to a dyed viscose rayon satin fabric (AATCC Standard of Fading No. 1). This color change constitutes one cycle and the specimens are said to have had a treatment equivalent to 6 months of actual exposure to average levels of NO_x, representative of NO_x levels at three separate locations in southern New Jersey. If the test specimens do not change color appreciably after one exposure cycle, the procedure is repeated (with the use of a fresh control sample) as many times as necessary to make an evaluation. Dyed fabrics are classified and rated according to the number of exposure cycles necessary to produce appreciable changes in shade. This method has become the accepted standard of comparison for all dyes. Experience has shown that consumers generally begin to complain when fading equivalent to slightly more than two exposure cycles has taken place.[24]

Laboratory Investigations

During and since the 1940's, much research has been carried out in an effort to understand gas fading and to develop ways of preventing it. Seibert[18] considered auto exhaust gases as a possible source of atmospheric contamination. He took acetate rayon fabrics that were colored with dyes having a known range in sensitivity to gas fading and exposed them directly to escaping exhaust gases. The fabrics with known sensitive dyes showed obvious color changes. He assumed the fading was caused by NO_x in the exhaust gases.

Ray et al.[8] found that, in the absence of sunlight, air (55°C, 50 percent RH) contaminated with SO_2 (about 150 ppm) and NO_x (150 ppm) caused decidedly less fading than NO_x (150 ppm) alone. The investigators attributed this difference to interactions between the gases. It is questionable, however, whether this result occurs at the low concentrations normally existing in urban environments.

Couper[25] demonstrated that severe gas-fume fading of a sensitive blue dye on acetate rayon bears a strong resemblance to sunlight fading. This evidence suggested that oxidation in addition to direct reactions (diazotization and nitrosation) between pollutants and dyes, is a more important gas-fume reaction than was previously realized.

In laboratory studies, Greenspan and Spoerri[20] found that essentially pure NO and NO_2 were both capable of fading sensitive dyed acetate fabrics, but that NO_2 was by far the more aggressive and powerful. In their studies, Salvin et al.[24] attributed practically all fading to NO_2. They showed that the mechanism of gas fading on acetate rayon is the relatively large absorption of NO_2 by this material and the low rate of reaction with it. The gas is, therefore, free to diffuse through the fibers and attack vulnerable dyes.

Gas-Fired Clothes Dryers

In the mid-1950's, the textile industry learned that dyed fabrics other than acetate and wool are vulnerable to fading by air contaminants. This conclusion was reached when dye chemists investigated a series of complaints that some colored (mainly blues) cotton fabrics were fading during the drying cycle in home gas-fired clothes dryers.[26] They traced the fading to NO_x formed during the combustion of natural gas used to heat the dryers. Fading occurred only while the textile materials were moist. Subsequent research (about 10 years later) confirmed the gas-dryer fading problem and revealed that NO_x levels (expressed as NO_2) in such dryers ranged from 1.1 to 3.7 mg/m^3 (0.6 to 2 ppm).[27]

Smog Study

One of the earliest field exposures designed to assess the effects of air contaminants on dyed fabrics was conducted in the summer of 1956.[28] Prompted by an increasing number of inquiries on fading, the Pacific Southwest Section of the AATCC carried out this study to determine the extent to which smog conditions may affect dyed textile fabrics. They selected 17 dyed fabrics, representing various classes of dyes and all the major fibers, and exposed them at two sites in the Los Angeles area, one considered a "heavy" smog area and the other a "light" smog area. The investigators placed two exposure chambers at each site. When closed, the chambers were thoroughly sealed; when opened, the fabric samples in the chambers were shaded from sunlight but exposed to the ambient air. One chamber at each site was opened only on smog days, the other only on "no-smog" days.

After exposure for 152 hours during smog days, 11 fabrics (acetates and nylons) developed visual color changes at the heavy smog site. At the light smog site, six fabrics developed color changes and the fading was less pronounced. Exposure for 152 hours during no-smog days produced visual color changes in six fabrics at the heavy smog site and in four fabrics at the light smog site. Results of this study clearly demonstrated that color changes were a function of smog concentration since the major pollutants in smog are NO_x and O_3. The investigators made no attempt to determine which pollutants caused fading in the individual fabrics.

AATCC Laboratory and Field Exposures

For many decades, the textile industry has been using outdoor lightfastness testing as a means of evaluating the fading characteristics of dyes. During lightfastness tests in the mid- and late-1950's, variations in color change were frequently observed on some dyed fabrics when exposed to equivalent amounts of sunlight and similar weather conditions but at different localities.[10-12] This abnormal behavior as a function of location was particularly evident in certain direct dyes on cotton and acid dyes on nylon. These observations prompted the AATCC Committee on Colorfastness of Textiles to Atmospheric Contaminants to conduct laboratory and field studies to assess the effects of air contaminants as a cause of anomalous fading.

The laboratory research included exposing a range of dyes on nylon, wool, and cellulosic fibers to the standard gas-fading procedure.[9] The investigators found that the most significant fading occurred on several direct-dyed cotton and viscose rayon fabrics. They concluded that ambient levels of NO_x existing in urban environments could be responsible for the anomalous results observed during lightfastness tests.

The AATCC Committee followed up the laboratory research by conducting service exposure trials in urban and rural areas.[10-12] (Details of methodology have been described previously in this chapter.) The Committee found that a number of dyed fabrics, including cotton and nylon in addition to acetate and wool, changed color. Furthermore, color changes were most pronounced in areas where NO_x and O_3 were both present. They concluded that (1) ambient levels of air contaminants, especially in urban areas, caused many of the observed color changes; (2) dyes vary in their vulnerability to chemical change by pollutants; and (3) color changes as a result of pollutants lead to variable results in lightfastness testing. The investigators suspected that, given acidic conditions, even minute quantities of NO_x would react to produce irreversible color changes in fabrics.[11]

A subsequent, more comprehensive, field study was conducted jointly by the AATCC and air pollution investigators with the Environmental Protection Agency.[13] (Details of this study have been described previously in this chapter.) An analysis of the results showed that NO_2 appeared to be one of the pollutants that caused fabrics to fade and that it was significant for seven of the exposed fabrics, though it was not necessarily the only pollutant responsible. In many cases, however, it was impossible to separate the effects of NO_2, as these were confounded with the effects of other pollutants.

Cellulosic Fabrics

The laboratory and field exposures furnished additional evidence of the type of fading observed on some dyed cotton fabrics after exposure in domestic gas-fired clothes dryers. The exposures also lent credence to complaints that some dyed cotton and rayon fabrics faded in warehouses and on the shelves of retailers;[29] textile people, however, tended to attribute this fading to light. The complaints, as well as the field exposures, revealed that fading occurred in certain blue and green shades, representing dyes from four major classes: direct, sulfur, vat, and reactive dyes. Laboratory exposure of these shades to the standard gas-fading test procedure did not normally produce fading. This test procedure, however, was designed to evaluate dyed acetate fabrics and has no provisions for controlling relative humidity because humidity is not a critical factor in acetate fading. Researchers, therefore, conducted follow-up laboratory exposures using the gas-fading test procedure under high-humidity conditions (probably greater than 50 percent). The results were dramatic; the same concentrations of NO_x that were previously ineffective produced under high humidity color changes that generally agreed with the field results. A somewhat different NO_x test procedure used in Europe results in high humidity conditions and has produced color changes on sensitive dyed cellulosic fabrics. Presently, the textile-dye industry in the United States is considering modifying the gas-fading test procedure to call for controlled-humidity conditions.

Controlled-Environment Study

Beloin[15] offers further confirmation of the fading effects of NO_x on sensitive dyes. He exposed 20 selected dye-fabric combinations for 12 weeks to various controlled environments of clean air contaminated with individual pollutants, including NO and NO_2. Nitric oxide concentrations were 120 $\mu g/m^3$ (0.1 ppm) and 1200 $\mu g/m^3$ (1.0 ppm); NO_2 concentrations were 90 $\mu g/m^3$ (0.05 ppm) and 940 $\mu g/m^3$ (0.5 ppm). As in previous research, Beloin found that NO was an insignificant cause in the fading of these fabrics. On the other hand, NO_2 was the most potent pollutant evaluated and was responsible for the greatest amount of fading on 13 of the fabrics. Fading occurred on cotton, rayon, acetate, and nylon fabrics, the rates of fading decreasing with time.

While the high exposure levels of NO_2 produced the most pronounced fading effects, low levels still caused readily visible color changes in a number of the fabrics. Relative humidity and, to a lesser extent, temperature were significant factors in accelerating fading. The exposure results also showed that fading in most cases is dependent on the nature of the fiber substrate. Acetate fabrics dyed with Disperse Blue 3 faded two to five times more than nylon fabrics dyed with the same dye. Likewise, Disperse Blue 27 on acetate faded severely, but the same dye on polyester did not fade.

Discoloration of White Fabrics

A recent problem, which has received little publicity but which is of considerable concern to the textile industry, is the yellow discoloration of pastel-colored or undyed white fabrics.[27-31] These fabrics may be woven from any number of common fibers, but most of the discoloration has occurred on nylon, acetate, and permanent-press (polyester-cotton) materials. Discoloration has usually occurred on items in storage or on display, including dresses, shirts, curtains, and lingerie. Returned items have represented major losses to some textile companies.

Since discoloration occurs mostly on white fabrics, dyes were ruled out as a source of the problem. Investigators turned to various additives, which are applied to fibers and fabrics to enhance certain properties. The additives tested included optical brighteners; cationic, antistatic, and soil-release finishers; softeners; and resinous processing agents. When tested by standard laboratory procedures, including the gas-fading procedure, many of these additives yellowed on exposure to NO_x. High relative humidity proved to be an important factor. Washing the fabrics sometimes removes the yellow discoloration, but this is impractical for items that yellow in warehouses or on display. The problem is best solved by selecting resistant additives. Such selections may be more expensive, but the textile industry and retailers recognize that some action must be taken to avoid an increasing number of complaints.

Protective Measures

To counteract the effects of gas fading, the textile industry has attacked the problem on two fronts: a search for resistant dyes and a search for gas-fading inhibitors. Dye chemists have been trying for several decades to synthesize acceptable dyes that would resist gas fading. Although gas fading is not limited to one dye class, research efforts have centered mainly on developing replacements for the sensitive anthraquinone disperse dyes for acetate fibers. These dyes are not equally sensitive to gas-fading; many shades are sufficiently resistant to meet all reasonable commercial and domestic needs adequately. Shades that are sensitive are mainly those in the blue range of the spectrum, especially the light and medium blues; they become redder on exposure to NO_x. Not all blues are sensitive, however, and some offer good resistance. The search for resistant blue disperse dyes received added impetus with the development of polyester fibers. Anthraquinone dyes possess excellent affinity for these fibers, but certain blue dyes with good lightfastness on acetate have unusually poor lightfastness on polyester. This fact emphasizes how fastness properties are dependent to a large extent on fiber substrate.[32]

Researchers have developed a number of "gas-fast" blue dyes, mainly by modifying the anthraquinone structure. This approach was desirable because dyes based on the anthraquinone structure possess excellent dyeing and lightfastness properties when applied to acetate fibers. On field testing these newly developed dyes, however, investigators found that ambient levels of ozone caused fading in some of them.[33] By further modifying the anthraquinone structure, dye chemists were able to develop a limited number of disperse dyes that retained their resistance to gas fading, but were more resistant to ozone fading. Fortunately, as gas-fading resistance increased, resistance to ozone fading increased, as did lightfastness on polyester fibers.[34,35]

The resulting dyes are now widely used despite their higher cost, low color buildup, and increased processing difficulties. For economic reasons, they are generally used only for light and medium shades on some moderate and most higher-priced fabrics; their poor color buildup precludes their use in dark shades, except for the most expensive fabrics.

The added cost and greater processing difficulties of the more resistant dyes brought about increased use of gas-fading inhibitors, especially on moderately priced fabrics. Inhibitors were initially developed for use on acetate fabrics, and today they are still used primarily on these fabrics. They are basic compounds that are applied to dyed fabrics to give them prolonged protection by either maintaining an alkaline condition on fabric surfaces or by reacting preferentially with NO_x.

Two types of inhibitors are widely used: fugitive and substantive.[24,36,37] Fugitive inhibitors, which include water-soluble aliphatic amines and alkaline salts, are applied to dyed fabrics during the finishing operations. These inhibitors effectively protect dyed fabrics by maintaining an alkaline condition on their surfaces; gas-fading reactions take place rapidly when surface conditions become acidic. Fugitive inhibitors have a serious drawback, however, because they are water soluble and subsequent washing by the consumer removes the protection. Nevertheless, such inhibitors serve a useful purpose by protecting fabrics during conversion into end products, storage, and display by retailers. They also can be used effectively on goods that are infrequently dry cleaned, such as women's dresses. Some fugitive inhibitors have a disadvantage besides water solubility in that they greatly reduce the lightfastness of direct and reactive dyes, some of which have been used to dye blends of acetate and cellulosic fibers.

Substantive inhibitors are aromatic amines that have an affinity for fibers and, therefore, are applied during the dyeing process. They are sometimes called permanent or codyed inhibitors. Although compounds initially found useful as inhibitors are weakly basic, they protect fabrics by preferentially reacting with NO_x; consequently, they delay the onset of actual fading enough to prevent complaints in all but the most severe cases of contamination. The reaction product, however, has a light yellow color that may or may not (depending on depth of shade and quantity of inhibitor used) impart an objectionable discoloration to fabrics. These inhibitors are not useful on pastel shades since the yellowish cast would be just as objectionable as gas-fading changes (blue shades will turn green instead of red). They also reduce the lightfastness of certain dyes for acetate fabrics.

The shortcomings of these earlier substantive inhibitors led chemists to develop new ones that were both substantive and nondiscoloring. The newer inhibitors possess less affinity for fibers, however, and thus provide less protection than the earlier ones. As a result, their overall effectiveness in many cases is limited. Unfortunately, they are least effective on fabrics colored with the more sensitive gas-fading dyes.

A successful means of preventing gas fading in synthetic fibers is to add colored pigments to the spinning solutions prior to the formation of the fibers into filaments or yarn. Pigments are generally resistant to the effects of air pollutants. Pigmented fibers and yarns can present problems, however, since there is a time lag of 6 to 8 months between their manufacture and their final conversion into end products. During this period, fashion colors can change dramatically. If fabrics are left undyed, on the other hand, they can then be dyed with the "in" fashion colors and converted into end products.

Although ways exist for mitigating the effects of gas fading, incidents still occur.[37,38] Fading of acetate linings on men's suits has been a particularly vexing problem. The most costly incidents have taken place during the storage of fabrics and end products in warehouses, with the result that entire truckloads of materials either had to be sold at prices below cost or returned to the producers. In an effort to ensure quality, some synthetic fiber producers offer the use of their fiber trademarks on labels only to customers that produce fabrics meeting established colorfastness performance standards for both pollutants and sunlight.[36,38] Consumers as well as producers benefit when such steps are taken.

OZONE

Discovery of "O-Fading"

Although dye chemists identified SO_2 and NO_x as possible dye fading agents during the early 1900's, it was not until the mid-1950's that Salvin and Walker[33] discovered that ozone was a cause of fading. The discovery came about as a result of the field testing of newly synthesized blue disperse dyes that had previously shown a high resistance to NO_x when evaluated by the standard AATCC gas-fading laboratory test method. Field testing was conducted to determine if the performance level of these new dyes was as favorable in actual use as that indicated by the accelerated gas-fading tests. In a preliminary 1-year service trial, investigators placed draperies in homes located in areas known to have either high or low levels of NO_x. The draperies were made from acetate fabrics dyed a variety of shades, with one of these newly developed dyes (Disperse Blue 27) as a color component. After exposure, a number of draperies showed a marked degree of fading. Furthermore, fading was generally greater than could be predicted on the basis of lightfastness and gas-fading laboratory tests. Color changes were most apparent on light shades and, in many instances, occurred in homes where NO_x levels were low. The investigators reasoned that some other atmospheric agent caused the fading.

As a result of this preliminary study, a more thorough and extensive service trial was conducted. Acetate draperies were dyed different colors, with some shades containing the new gas-fast dye, Disperse Blue 27, as one of the color components; others contained gas-fading sensitive dyes along with inhibitors. The draperies were placed in homes in Pittsburgh, Pennsylvania, an industrial complex noted for the prevalence of gas-fading; in Ames, Iowa, a nonindustrial town known to have minimum levels of NO_x; and in Austin, Texas, a nonindustrial city where natural gas is the main fuel used. After exposure for 6 months, color changes were evident in many of the draperies at all three locations and became even more pronounced at the end of 12 months. Color changes occurred in areas of the draperies that were not exposed to sunlight. As was found in the preliminary service trial, draperies containing the gas-fading resistant blue-dye component faded as much, and in some cases more, at locations (Ames) having low levels of NO_x than at locations (Pittsburgh) with higher levels. Relative levels of NO_x were confirmed by rapid reddening of gas-fading standard control samples in Pittsburgh and lack of reddening in Ames. Furthermore, at all locations some draperies showed considerably more fading than accompanying gas-fading control samples. Much of the observed fading was characterized by a bleached, washed-out effect, rather than the familiar reddening that nitrogen oxides produce in most gas-fading sensitive dyes. Again, this anomalous behavior suggested that some other oxidizing agent was responsible and was present at all sites, although concentrations appeared to be somewhat less at Pittsburgh.

To describe this fading phenomenon, Salvin and Walker[33] coined a new term, "O-fading." On reviewing the various chemical constituents in the atmosphere that could produce this bleaching effect, they concluded that ozone, or ozone in conjunction with other oxidizing agents, was the most likely cause on the basis of the following suppositions, general observations, and laboratory investigations:

1. Fading on gas-fading resistant dyes observed during the service trials in nonindustrial areas may be attributed to background levels of ozone, augmented by small amounts produced photochemically. O-fading was either absent or less evident in Pittsburgh because much of the atmospheric O_3 was consumed in oxidizing ambient SO_2 to SO_3. Pittsburgh was known to have above average levels of SO_2.
2. Drapery fabric samples that were sensitive to O-fading developed shade changes similar to the anomalous effects produced during the service trials when they were exposed in a light-tight chamber containing ozone generated from ozone lamps. Ozone did not fade dyed fabrics known to resist fading during service trials.
3. Antioxidants applied to fabrics sensitive to O-fading effectively inhibited the bleaching action of O_3. Some of the widely used gas-fading inhibitors are active antioxidants and consequently inhibit O-fading as well as gas-fading. This fact undoubtedly obscured earlier detection of the O-fading phenomenon.

Salvin and Walker[33] also investigated the ozone-fading characteristics of gas-fast Disperse Blue 27 on other fibers: cellulose triacetate, polyester, acrylic, and nylon. Acrylic and nylon showed no evidence of fading. (A few years later, however, researchers were to discover that nylon fibers dyed with Disperse Blue 3 develop pronounced color changes when exposed to O_3 in the presence of high relative humidity.) The sensitivity of cellulose triacetate and polyester fibers to O_3 was found to be dependent upon the dyeing and finishing conditions used in processing the fabrics. If these conditions are such as to ensure maximum penetration of dyes into fibers, the resistance of the fabrics to O-fading will significantly increase. For these fibers, therefore, heat treating, which increases dye penetration and can be conducted during the dyeing and finishing operations, is necessary to ensure greater resistance to O-fading. This treatment changes the internal arrangement of fiber molecules, resulting in a more closely packed intermolecular structure that slows down the diffusion rate of O_3. For polyester fibers, the use of carriers also increases dye penetration.

In evaluating other disperse dyes, the researchers found that O-fading, like gas-fading, occurs to the greatest degree with anthraquinone blues and some reds and, to a lesser extent, with several of the azo reds. They also noted that most of the substantive gas-fading inhibitors are sufficiently strong antioxidants to reduce the rate of O-fading. For the highest overall level of colorfastness toward atmospheric fading, gas-fast dyes together with gas-fading inhibitors or other antioxidants are recommended.

Standard Test Method

Once ozone had been established as the principal active agent in the atmosphere responsible for O-fading, the AATCC Committee on Colorfastness to Atmospheric Contaminants took steps during the late 1950's and early 1960's to develop a testing method. Their efforts culminated with the approval and publication in 1963 of a procedure that presently is designated as Test Method 109-1972, Colorfastness to Ozone under Low Humidities.[23] This method has been useful in predicting fabric performance upon service exposure to O-fading environments. It calls for simultaneously exposing test specimens and an O-fading control sample (AATCC Control Sample No. 109) in a chamber containing circulating air contaminated with O_3. Exposure, which is carried out at ambient room temperatures and relative humidities not exceeding 65 percent, continues until the control sample shows a color change corresponding to a standard of fading (AATCC Standard of Fading No. 109). This exposure period constitutes one cycle, and the test specimens are said to have a treatment equivalent to 4 to 6 months of actual exposure to moderate levels of ambient ozone.[39] If the test specimens do not fade appreciably, the cycles are repeated until the specimens show a definite color change or until a prescribed number of cycles has been completed. Ozone may be generated by O_3 lamps, or by a high-voltage insulated-grid design that produces O_3 by corona discharge. The test method does not specify the O_3 exposure concentration; generally, however, it does not exceed 100 parts per hundred million (pphm) and normally is about 25 pphm when commercially available equipment is used.[40]

The control sample, frequently called the ozone-fading control ribbon, is a medium-gray cellulose triacetate fabric, prepared as a tertiary shade by dyeing with O-fading vulnerable Disperse Blue 27, relatively resistant Disperse Red 35, and resistant Disperse Yellow 42. The sample shows O-fading mainly by a loss of blue and takes on a bleached, washed-out silver gray appearance. The bleaching effect is the result of the almost colorless products that O_3 produces when it reacts with vulnerable dyes. The loss of blue is more readily recognized in the tertiary shade than in a single shade of blue. Fading does not proceed uniformly with time; it is more apparent in the earlier stages of the fading cycle. Slightly more than two cycles produce sufficient fading to cause consumer complaints.

Anomalous Fading During Service Trials

The discovery that O_3, in addition to NO_x, is a prime cause of fading was useful in explaining much of the anomalous fading of certain dyed fabrics that was observed during subsequent lightfastness testing and service trials. Abnormal fading was first noticed during lightfastness testing in the late 1950's.[41] Certain fabrics exposed at different nationwide localities but to the same total amount of solar radiation (Langleys) revealed unexpected fading. For example, a decidedly larger number of fabrics faded more at a semirural site near Sarasota, Florida, than at a semirural site near Phoenix, Arizona, or at a semi-industrial site in greater Chicago, Illinois. Abnormal fading was especially prevalent in certain direct dyes on cotton and acid dyes on nylon. An analysis of the temperature and relative humidity conditions during exposure was only partly helpful in explaining the abnormal fading. Other factors were influencing the color change and air contaminants were suspected.

Anomalous fading behavior was also observed in a follow-up field study that Schmitt conducted.[10,42] He exposed cotton fabric samples, dyed with certain direct dyes, for 24 days in Los Angeles, California; Fair Lawn, New Jersey; Sarasota, Florida; and Phoenix, Arizona. Samples were exposed to direct sunlight under glass and also shaded from direct sunlight. The exposure design allowed intimate contact between fabric samples and ambient air. As was expected, pronounced fading developed on shaded samples exposed in the photochemical atmosphere of Los Angeles. At the semirural site near Sarasota, however, Schmitt also observed appreciable fading on the shaded samples; in some cases, it was equal to the fading observed from exposure to direct sunlight. He reasoned that the high relative humidity normally prevailing in Florida was the controlling factor in causing abnormal fading. Additional research showed that high humidity by itself caused only a portion of the observed fading. More important, Schmitt concluded, was the resulting increase in the equilibrated moisture content of the cotton fabrics. The high moisture content promoted and accelerated the absorption and reaction of air contaminants with vulnerable dyes within the fibers. Schmitt stated that much of the abnormal fading observed in Florida appeared to be caused by air contaminants. Later studies indicated that ozone was largely responsible for this anomalous fading in Sarasota.[12]

In service exposure trials in 1961, the AATCC Committee on Colorfastness of Textiles to Atmospheric Contaminants exposed a wide range of dyed fabrics for 90 days in the absence of sunlight, but with free access to ambient air.[12] The exposure test sites were located in Los Angeles, Chicago, Phoenix, and Sarasota. (Additional details were given previously in this chapter.) A number of dyed fabrics faded excessively in Los Angeles because of the combined action of relatively high levels of O_3 and NO_x. Fading was generally less severe on like fabrics exposed in Chicago, where the atmosphere had lower levels of O_3 but fairly high levels of NO_x. Anomalous fading was observed at the semirural sites in Phoenix and Sarasota. Since both areas were essentially free of NO_x (indicated by a lack of reddening of NO_x control samples) but contained appreciable amounts of O_3 (indicated by the bleaching effect on O-fading control samples), the observed fading was attributed largely to O_3. The degree of fading, however, was greater in Sarasota than Phoenix. The investigators concluded that high humidity, normally found in Florida, accelerated the ozone-dye reaction as Schmitt had previously suggested.

In the spring of 1963, investigators exposed a number of dyed fabrics in Sarasota in order to compare their fading characteristics both in direct sunlight and when shaded from direct sunlight.[12] Exposure for 30 days to this humid, semirural environment, contaminated with moderate levels of O_3 and essentially free of NO_x showed that those dyed fabrics most susceptible to O-fading were also those that faded the most in sunlight. This result was not surprising since fading by sunlight is largely a photochemical oxidation reaction.

The results of the service trials emphasized the importance of O_3 as an effective fading agent, and focused attention on the critical role of relative humidity. They also alerted the textile industry to the possibility of potential consumer complaints. Such complaints, which were not long in coming, concerned mainly two distinctly different textile materials: polyester/cotton permanent-press fabrics and nylon carpets. In both cases, complaints began to appear in the early 1960's. These problems were not generally made known, however, because adverse publicity could have jeopardized the use of these fibers before researchers had an opportunity to assess the cause of fading and take corrective measures.

Permanent-Press Fabrics

Initial complaints concerning polyester/cotton permanent-press fabrics were a result of fading on the folds and edges of slacks stored in warehouses or on the stock shelves of retail outlets.[31,43] Incidents occurred in various locations including California, Texas, and Tennessee. Because of the volume of garments involved, some producers suffered heavy economic losses. Fading was marked by a loss in blue, along with a slight increase in red, suggesting that O_3 and, to a lesser degree, NO_x may have been the active fading agents since sunlight was obviously not a factor. This conclusion did not seem reasonable, however, because most vat dyes on cotton and disperse dyes on polyester fibers are resistant to fading by common air contaminants. Furthermore, fading occurred only on fabrics that had been made into finished products and cured to set the permanent-press resin; fading had not been observed during the temporary storage of dyed fabrics, either before or after treatment with permanent press resins (prior to curing).

After a thorough investigation that included extensive laboratory tests, researchers found ozone to be the major fading agent, with NO_x also capable of causing fading but to a lesser extent. The fading mechanism, which is unique and complex, takes place as a result of the curing operation and involves the disperse dyes used to color the polyester fibers rather than the vat dyes on the cotton. During curing, some disperse dyes partially migrate to the permanent-press finish, which is a combination of reactant resins, catalysts, softeners, and nonionic wetting agents. The dispersed dyes migrate to the solubilizing agent (nonionic surfactants and softeners) in the finish and are then in a media in which fading by air contaminants can easily occur. Softeners are especially effective media for absorbing gases.

The choice of catalyst used in the finish plays an important role, as the migration of disperse dyes increases significantly when magnesium chloride is used as a catalyst rather than zinc nitrate. Magnesium chloride is capable of forming complexes with certain anthraquinone disperse dyes (blues and red), and these complexes are soluble in the resin finish.

The blue disperse dyes that faded on the permanent-press fabrics are the same ones that, when used on cellulose acetate, are sensitive to fading by O_3 and NO_x. Fading takes place rapidly on cured garments dyed with vulnerable disperse dyes and finished with a resin system containing a magnesium chloride catalyst. Garments have faded after storage in warehouses for only 10 days.

Several remedial measures are available that, if followed, will markedly reduce the possibility of fading permanent-press products. These include: (1) replacing the vulnerable anthraquinone dyes with dyes that resist migration (high sublimation resistance), such as the azo disperse dyes;[44,45] and (2) carefully selecting the materials that make up the permanent press finish; that is, avoiding magnesium chloride as a catalyst and using softeners and surfactants that show less tendency to serve as solubilizing agents.[46] As long as the textile industry takes these steps, fading of permanent-press garments by O_3 and NO_x can be essentially eliminated.

Nylon Carpets

Fading complaints concerning nylon carpets originated mainly in the warm humid areas from Texas to Florida and, as a result, became known as "Gulf Coast fading."[31,43] In one case, nylon carpeting in a Texas apartment complex faded 30 days after installation. A few incidents were noted also along the East Coast and in the Los Angeles area. Fading occurred on carpets manufactured from both nylon 66 and nylon 6 fibers. Disperse dyes were used because many possessed the easy leveling properties so necessary to avoid dye streaks. Fading took place largely on those carpets dyed with Disperse Blue 3 as a color component. Avocado, a tertiary-dyed dull-green shade, was a particularly sensitive color, and fading was characterized primarily by loss in blue as the green color gradually turned to a dull orange shade.

Investigators eliminated sunlight as a primary cause of fading since complaints occurred in rooms where light intensity was low. Exposure of carpet samples to AATCC standard test methods for O_3, NO_x, and SO_2 also failed to duplicate the color change. Since fading complaints occurred in humid environments and previous lightfastness testing and service trials established that conditions of high relative humidity promote fading of certain dyes by ozone, the investigators next exposed carpet samples to O_3 in the presence of high relative humidity (85 to 90 percent). Under these conditions, pronounced fading took place on those samples containing Disperse Blue 3, and the fading was similar to color changes observed in homes along the Gulf Coast. Later experiments showed that relative humidity must be somewhat above 65 percent for pronounced ozone fading to occur.

Similar avocado carpet samples were also exposed outdoors in Florida. Samples were shaded from direct sunlight and placed 10 inches from the ground to ensure exposure to maximum ambient relative humidity. Exposure periods ranged from 1 week to 30 days. The carpet samples developed pronounced color changes. Fading was attributed to O_3 on the basis of observed color changes in ozone control samples and lack of reddening of nitrogen oxides control samples.

Research on the mechanism of fading showed that the heat-treating method used to texture nylon filaments was a most important factor. Texturing geometrically modifies or otherwise alters fibers to change and enhance certain basic physical characteristics such as bulk and resilience. Researchers found that the rate of fading by O_3 was significantly less in nylon fibers textured by dry heat than in those textured by steam. Steam texturing produces a somewhat open fiber structure that more readily absorbs moisture, especially when the humidity is high, which results in increased swelling and greater surface area. Increased fiber surface area and moisture content favor increased O_3 diffusion and greater subsequent fading rates.

Today, Gulf Coast fading can be mitigated or totally prevented by (1) using nylon fibers that have been modified and textured to decrease the accessibility and diffusion rate of ozone; and (2) using dyes having improved resistance to ozone fading. Nylon carpet fiber producers recommend that selected acid dyes having satisfactory leveling properties be used for maximum resistance to fading. For intermediate resistance, they recommend the use of improved disperse dyes or combinations of acid dyes and improved disperse dyes. Under no circumstances do they endorse the use of Disperse Blue 3.

Cellulosic Fabrics

Although less serious than the previously described problems, scattered incidents of fading on cotton and rayon fabrics also came to the attention of the textile industry during the early 1960's and are still occurring today. Consumer complaints have included fading of direct dyes on cotton upholstery, of sulfur dyes on corduroy fabrics, and of reactive dyes on printed draperies.[43] Previous outdoor service trials had shown that a number of dyed cellulosic fabrics faded even though their exposure to standard laboratory test procedures failed to produce significant color changes. As was true for nylon carpets, researchers found that relative humidity was the controlling factor. Exposing certain dyed cellulosic fabrics to high-humidity environments contaminated with O_3 or NO_x, or combinations of these pollutants, produced fading similar to that observed during service trials and on returned "consumer complaint" articles.

High Humidity Test Method

The unexpected fading of nylon carpets by O_3 was a costly experience for the textile industry and demonstrated the need for a test method to evaluate colorfastness to O_3 under high-humidity conditions. The AATCC Committee on Colorfastness to Atmospheric Contaminants fulfilled this need during the late 1960's by developing Test Method 129-1972, Colorfastness to Ozone in the Atmosphere under High Humidities.[23] The principles and procedures involved in this test are similar to previously described Test Method 109-1972 except that exposure conditions are maintained at 85 to 90 percent relative humidity and $40 \pm 5°C$, with ozone concentrations ranging from 374 $\mu g/m^3$ (20 pphm) to 1680 $\mu g/m^3$ (90 pphm). The control sample is an avocado shade of nylon 6 fine-gauge tufted carpet tertiary-dyed with Disperse Blue 3, Disperse Red 55, and Disperse Yellow 3. The standard of fading used is similar carpet material dyed to a shade representing an average degree of fading that control samples develop after 30-day exposures in southern Florida in the absence of sunlight for a 1-year period. Control samples yield shade changes after two cycles that are equivalent to changes observed on consumer complaint fabrics from Florida and Los Angeles.[47] This test method has been useful in predicting the behavior of textile materials in actual service and in preventing costly, wide-scale fading by ozone.

The U. S. Department of Housing and Urban Development is planning to include a carpet performance standard for resistance to O_3 fading as part of the FHA carpet certification program. AATCC Test Method 129-1972, or a modification thereof, may be the designated test procedure.

Recent Exposures

Environmental Protection Agency investigators, in cooperation with the AATCC, conducted field and laboratory exposures of selected dyed fabrics. In the field study[13] (discussed previously in this chapter), ozone seemed to be one of the pollutants causing fading and was a significant factor (though not necessarily the only pollutant responsible) in the fading of the exposed fabrics. It was generally impossible to separate the effects of O_3 because they were confounded with the effects of other pollutants, especially NO_x.

The controlled-environment laboratory study[15] was designed to assess the effects of common air pollutants, temperature, and relative humidity on the colorfastness of certain dyed fabrics selected from those exposed during the field study. (Additional laboratory exposure details were discussed previously in this chapter.) Fabric samples were exposed to two concentrations of ozone: 100 $\mu g/m^3$ (0.05 ppm) and 980 $\mu g/m^3$ (0.50 ppm). As might be expected, under similar exposure conditions, high ozone levels produced significant fading in more fabric samples than low levels, and, furthermore, the color changes were more pronounced. Low ozone levels, nevertheless, produced visible fading in a number of sensitive fabrics, an important finding since the low levels were similar to levels frequently occurring in metropolitan areas. The study also demonstrated that high relative humidity (90 percent), and, to a lesser extent, high temperature (32°C) are significant factors in promoting and accelerating ozone-induced fading, thus confirming what investigators observed during previous service trials. Rate-of-fading curves did not follow any consistent pattern, but were obviously dependent on such factors as color and type of dye, fiber substrate, and environmental conditions.

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CHAPTER 4

INDUSTRIAL AND COMMERCIAL AWARENESS

IMPORTANCE OF COMMUNICATION

Awareness by the textile industry of air pollution effects on textile fibers and dyes is an important aspect of the overall effects problem, since the greater the knowledge and understanding, the more likely that corrective measures will be taken. To a large extent, awareness depends on information provided by product users, and similarly the industry, on uncovering new problems involving air pollution effects, must disseminate the data to industrial and commercial customers. These customers are then alert to the possibility that some of the damage brought to their attention may be caused by air pollution, and they, in turn, are more likely to convey complaints to the industry for subsequent follow-up investigation.

Despite the clear need for effective communication about the effects of air pollution on textiles, a vital element is lacking: information from consumers. Unfortunately, they, as a group, do not register many complaints; and, while they may openly discuss complaints with friends and neighbors, adversely affecting the reputation of stores and product brand names, few complaints reach the retailers. This difficulty is intensified when those consumers who do register complaints meet with little or no success; they become discouraged and develop an attitude of futility. In essence, therefore, while retailers do receive a fair number of complaints, they represents only a small fraction of total consumer dissatisfaction.

The fading of colored textile fabrics is a frequent complaint of consumers and may serve as an example of their attitudes, since potential causes of fading include air pollutants in addition to sunlight, laundering, and dry cleaning. Fading may take 6 to 12 months or more to develop, and consumers generally take a somewhat passive attitude on discovering the problem. Many feel that fading, though objectionable, is normal and must be accepted. They also may assume that, since they no longer have their sales receipt, it is too late to take effective action. The few who do register complaints frequently meet resistance because many retailers tend to blame fading on sunlight, an admittedly important factor but not necessarily the cause. Furthermore, retailers consider fading by sunlight a shared responsibility. Often they make adjustments and return the goods to apparel or home-furnishings producers. In most cases, the producers take no further action because they have neither sufficient information to diagnose the complaints nor facilities to determine the causes. It is more economical to pay for isolated complaints than to undertake expensive diagnoses. Thus, lines of communication between consumers and producers break down to the disadvantage of both. Consumers are dissatisfied with the performance of their purchases, and, consequently, the merchandising efforts of retailers and producers in promoting quality performance and brand names become less effective.

When the economics justify it, producers respond quickly to complaints. For example, when incidents involve the possible fading or discoloration of fabrics or garments in warehouses or on display shelves of retailers, the resulting complaints, whether made to fiber producers, fabric mills, or dyers and finishers, may become major financial burdens, because thousands of items may be affected. Such complaints obviously receive immediate attention, and subsequent investigations have produced important technical information, much of which has been the basis for establishing industry-wide testing procedures. The American Association of Textile Chemists and Colorists is actively engaged, for instance, in developing test procedures for examining the fading of colors from exposure to atmospheric pollutants.

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AWARENESS

To measure the degree of awareness of the various textile-related industrial and commercial groups, Dr. Salvin in conducting his textile-effects survey, made numerous inquiries to collect information on damage problems directly caused, or suspected of being caused, by air pollution. He solicited responses from producers of fibers, fabrics, dyes, and finishes; fabric dyers and finishers; apparel, carpet, drapery, and upholstery manufacturers; chain and department stores; laundry and dry cleaning establishments; trade and technical associations; consumer groups; and Federal, state, and university research centers.

The survey showed that the degree of awareness of air pollution problems in the industry varied with particular textile areas of interest. In order to assess awareness effectively, Dr. Salvin divided the diverse industrial and commercial respondents into five product-oriented groups: fiber products; dye and specialty chemical manufacturers; fabric mills, dyers, and processors; producers of apparel, home furnishings, and other goods; and consumer-oriented groups.

Fiber Producers

Fiber producers (including both those concerned with manmade fibers and organizations that supply, promote, and conduct research on natural fibers) are aware that air contaminants can produce serious problems. Manufacturers of manmade fibers appear, however, to have a better understanding of these problems, probably because dye fading (the major problem area) is much more prevalent on fabrics made from synthetic fibers than natural fibers. They maintain close liaison with producers of dyes and textile specialty chemicals; some large corporations even have divisions that manufacture both fibers and dyes. This close relationship is advantageous because fiber producers, by introducing processing changes, may be able to modify their fibers so as to overcome difficulties that become evident during dyeing operations. Fiber producers also work closely with fabric mills in the mutual recognition of dye-fading and fabric-deterioration problems. In addition, producers of manmade fibers find it in their interest to know as much as possible about their own fibers, as well as those of their competitors, in order to promote and protect their brand names. Some producers require that fabrics made from their fibers and carrying their brand names meet certain standards of resistance to fading by oxides of nitrogen and ozone.

Dye and Specialty Chemical Manufactures

Fabric mills encountering color-fading or fiber-deterioration complaints have traditionally submitted these problems to dye manufacturers or suppliers of various textile specialty chemicals. As a result, these manufacturers and suppliers as well as their trade association, The Dye Institute, are well aware of the problems associated with air pollution. The major dye manufacturers have evaluated the fading resistance of their dyes against NO_x, acids, and ozone. Specialty chemical companies have developed numerous inhibitors and other additives to protect dyed fabrics against air pollutants. Accordingly, these manufacturers and suppliers promote and publicize in advertisements the virtues of their products in resisting the effects of air pollution.

Fabric Mills, Dyers, and Processors

The American Textile Manufacturers Institute is a trade association with an extensive membership consisting of manufacturers, dyers, and processors of fabrics for use in apparel, home furnishings, and industry. Some of the fabric manufacturers also produce finished consumer goods. In his survey, numerous cooperating members of this organization furnished Dr. Salvin specific information on various problem areas caused by air pollution; thus, definitely establishing that they were aware of the problem. This awareness was especially apparent in the case of the major fabric mills, which are quality-conscious and are constantly endeavoring to identify their brand names with quality products. Some mills, together with their associated dyehouses and finishers, must meet stringent performance specifications that fiber producers, converters, and large chain retail organizations have imposed. Fiber producers will not allow the use of their brand names if fabrics do not meet certain specifications. Also, the major mills seem, in essence, to have the technical competence to recognize and evaluate complaints once they have been established. It should be pointed out, however, that more recent information relative to the fading of dyes on cotton and rayon and to the discoloration of whites has not yet been fully recognized and dealt with by the textile industry.

While the major fabric mills strive to produce quality products, some mills and dyehouses do process goods of lower competitive costs, using dyes and finishes that are vulnerable to air pollutants. They are aware that pollution can cause trouble, but are willing to take the risk that no major problems will develop or, if problems do develop, that complaints will be scattered and not economically important.

Producers of Apparel, Home Furnishings, and Other Goods

Within a sizable and diverse group of many large and small producers of various types of apparel, upholstered furniture, carpets, and miscellaneous finished textile goods, a number of trade associations are active, and most of them are aware of the problems that air pollutants may cause. For example, the American Apparel Manufacturers Association has recently distributed a bulletin to its members alerting them to potential fading damage by ozone in some permanent-press fabrics. The National Association of Hosiery Manufacturers has been aware for some time that acid aerosols may attack nylon stockings and cause runs; they have warned their members of this problem. In addition, textile testing laboratories, including the Good Housekeeping Guaranty Seal, American Institute of Laundering, U. S. Testing Company, Better Fabrics Testing Bureau, and the American Standards Association (L-22 Standards), have specifications for colorfastness to NO_x and ozone. These specifications have been recommended by various trade organizations within the textile industry as levels of performance that meet consumer expectations.

For the most part, the large textile producers, especially those who have stressed quality products and have developed close ties with fiber and fabric producers, are aware that air pollution may cause problems. Despite the efforts of trade associations, however, the smaller producers have been slow to develop awareness. This attitude appears, however, to be changing as concern for the environment gains more public attention.

Consumer-Oriented Groups

Awareness varies widely among the many individuals and organizations dealing directly or indirectly with consumers, including the various retail chain and department stores, laundry and dry cleaning establishments, and home economics interests. An early indication of awareness by a retail outlet is gained from Labarthe's[1] interesting study. He surveyed over 10,000 complaints submitted by a major department store in Pittsburgh to the Mellon Institute for analysis during the years 1935 through 1953. All the complaints were divided into two categories: customer faults and merchandise faults. Customer faults, which made up about two-thirds of all the complaints, included mainly damage problems that customers brought on themselves by misusing the merchandise or failing to follow label directions. Of the remaining one-third of the complaints (merchandise faults), Labarthe found that gas fading was one of the most common causes. For example, it caused one-half (193 cases) of all merchandise faults on women's acetate dresses.

Labarthe documented for one chain of retail stores (Table 4-1) the number of customer complaints attributed to gas fading on women's dresses made from all the principal fibers. The number of fading complaints is expressed as a percentage of the total number of registered complaints, including both customer and merchandise faults.

The data reveal that serious problems existed during the 1930's and mid-1940's and that subsequent corrective measures resulted in a significantly reduced number of complaints. Obviously, during these years, this retail store knew of the effects of air pollution, but this awareness was not typical of similar "non-chain" retail outlets.

The large chain type department stores, such as Sears, Penney's, and Macy's, understand the various damage problems that air pollution can cause. They have established performance specifications that their suppliers must

Table 4-1. CUSTOMER COMPLAINTS ABOUT FADING ON WOMEN'S DRESSES

Time interval, yr	Fading complaints, % of total complaints
1935-41	8.1
1942-45	23.8
1946-47	6.2
1948-49	5.6
1950-51	2.8
1952-53	2.1

meet, and most have quality control laboratories that check incoming merchandise against these specifications. In addition, their suppliers, especially for such items as draperies and home furnishings, have become familiar with the fading effects of air pollution and have taken remedial steps to reduce such occurrences.

These efforts by the large retail chain stores and their suppliers have resulted in a gradual reduction of consumer complaints in recent years. Currently, these stores report that the complaints about textiles that are traced to air pollution are relatively few and not considered serious. Even in the past, however, the number of registered complaints has been fairly low as is apparent from the fact that, of the many retail outlets queried, none had ever organized their complaint records to show air pollution as a cause. Of course, this evidence does not necessarily mean that damage from air pollution was insignificant. Consumers have many complaints that go unreported, and sometimes they are not even aware that damage has occurred, especially in the case of color fading in which the effect is insidious and often goes undetected until clothes come out of storage or come back from the dry cleaner.

Various trade associations that are consumer-goods oriented are aware that air contaminants can impair textile goods and have alerted their members by periodically sending out information bulletins. Many retail outlets and merchants, however, especially the smaller ones, depend on their suppliers to furnish them with quality merchandise. Apparently, the information supplied in the bulletins is seldom passed on to the sales clerks, who mainly deal with customers and, in many instances, receive and adjust complaints. As a result, air pollution damage is usually not suspected of causing complaints.

Dry cleaning and laundering trade associations are also aware that air pollution can damage fabrics. They have warned their members that various color-fading problems can occur and that consumers may attempt to blame fading on previous dry cleaning or laundering operations. The National Institute of Dry Cleaning keeps abreast of the types of problems its members encounter by annually processing a large number of complaints that individual members submit because they are unable to establish the cause clearly. In 1967, the Institute attributed 727 complaints to gas fading. Medsker[2] compiled information on complaints from files of the Detroit Dry Cleaning and Laundry Institute and found that atmospheric fume fading was a frequent cause. In 1962, consumers registered the most complaints in October, November, and December, the months that many garments come out of storage. Likewise, Pollock[3] found that a majority of dry cleaners and retailers surveyed in a national sample (early 1960's) regarded gas fading as a major factor in causing color change.

Home economists also are aware of the damage air pollutants can produce, and some academic groups in this field have conducted research on air pollution effects. In a study of the significance of consumer textile complaints, Quinn,[4] a member of the consumer interests committee of the American Home Economics Association, emphasized that consumers, by registering legitimate complaints, play an important role in helping to develop textile standards.

These standards naturally work to the advantage of consumers since they establish minimum end-use requirements for a variety of textile fabrics.

CONCLUSIONS

On the basis of information solicited from a wide range of textile interests, awareness of the effects of air pollutants on textiles and dyes is generally strongest among those parts of the industry farthest removed from contact with the consuming public. Thus, the manufacturers of fibers, dyes, and specialty chemicals are conscious of the effects of air pollution. Such awareness is found also among most of the fabric producers and dyers.

Manufacturers of apparel and home furnishings and the numerous retailers show a mixed degree of awareness, with the larger organizations generally more conscious of the problem than the smaller ones. Many of these organizations have quality control laboratories and have issued performance specifications that merchandise from their suppliers must meet. To various degrees, all within this general group depend on their suppliers to furnish quality products, especially those suppliers with well-publicized brand-names. The suppliers must concentrate on producing quality products in order to protect the gains resulting from their brand-name promotional efforts.

Because of the general reluctance of consumers to complain and because awareness at the retail level is weak, many textile problems caused by air pollution go unreported or unidentified. Since complaints serve an important function in identifying and establishing problems at the manufacturing level, consumers should be encouraged to report them. Likewise, the retail trade should alert their sales people to the problems that air pollution can produce so that they can at least suspect it as a possible cause for complaints. Therefore, in order to establish an accurate record of the damaging effects of air pollution on textile products, increased awareness, as well as better communications, must be developed among consumers, retailers, and producers.

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CHAPTER 5

CONSUMER AWARENESS*

INTRODUCTION

As noted in previous chapters, researchers have documented considerable evidence on the adverse effects of air pollution on textile fibers and dyes. They have shown by laboratory tests and service exposure trials that various problems can be caused by air contaminated with small amounts of one or more of the following: SO_2, NO_x, ozone, and particles (soiling). As discussed in Chapter 4, however, awareness of the various problems that polluted air can produce is generally strongest among such interests as fiber and dye producers, which are farthest removed from the consuming public. In fact, the gap between scientific evidence and public knowledge may be substantial.

In order to arrive at a more positive measure of this gap, Dr. George B. Sproles, a research economist and member of Dr. Salvin's staff, conducted a public survey that focused on consumer awareness of the detrimental effects of air pollution on textile products. This exploratory survey was carried out in Philadelphia, Pennsylvania, during the winter of 1970. Details and results are reported in this chapter.

The decision to measure consumer awareness of the detrimental effects of air pollution on household textile products was made only after carefully evaluating its overall importance. On the basis of a subjective analysis, consumer awareness of the effects of air pollutants on textiles and dyes was judged to be important because of the impact it would have on goods and services. Consumers having such awareness are likely to (1) be alert to problems potentially caused by air pollutants; (2) report to retailers those problems that normally would go unreported, and thus may receive better adjustments; (3) question the resistance of fibers and dyes to air pollutants and will, therefore, indirectly demand better merchandise; and (4) demand a cleaner environment and thus have political impact.

In the absence of studies that shed light on how consumers react to new information about the effects of air pollution on textiles (awareness), the statements above may be subject to question. Admittedly, consumers are a variable group, and individuals do handle new information in different ways. Some may immediately dismiss it as irrelevant and unimportant, while others may make maximum use of it; many will react in a manner somewhere between these extremes.

Socioeconomic factors strongly influence consumer reaction. For example, where consumers live is most important; those living in low-pollution areas have little use for effects information, and therefore awareness is not significant. Effects information could be useful, however, for the majority of the population who congregate in urban areas where pollution can be severe and problems are more likely to occur. Income is another important factor. Low income families are more concerned with the day-to-day problems of life, while middle and upper income families are more likely to take notice of textile problems and question the influence of air pollution.

In evaluating the importance of consumer awareness, researchers subjectively took into account all of these socioeconomic factors. The overall consensus was that consumer awareness was important and that the public would benefit by becoming more aware of the effects of air pollution on textile products. Furthermore, a measure of consumer awareness is necessary to assess the need for public information programs and to make improved estimates of economic losses.

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*The information presented in this chapter is taken from a paper entitled, ***Public Awareness of Air Pollution Damage to Textile Products: A Survey of Homemakers***, by George B. Sproles, who is currently on the faculty of Purdue University.

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BACKGROUND

To gain background information for planning, designing, and analyzing the Philadelphia survey, the investigators reviewed and examined several important issues. They considered: (1) public awareness as it relates to air pollution in general, (2) the dissemination and public awareness of information on air pollution damage to textiles, (3) the unique characteristics of textile products, (4) the influence of socioeconomic factors on public awareness of air pollution, and (5) various survey research techniques available for assessing consumer experiences with air pollution.

Public Awareness of Air Pollution

Air pollution publicity in recent years virtually ensures public awareness of this environmental problem, particularly in urban areas, where active regional newspapers and pollution control organizations have supplemented the efforts of the national media. Emphasized in recent Presidential State-of-the-Union messages, pollution control has become a political issue of national significance. College students and environmental activists have shifted their attention to ecology and the preservation of the environment. Trends clearly indicate an increase in public awareness of environmental problems.

While pollution control may have only recently received widespread public attention, the issues and questions related to air pollution have been acknowledged for many years. Federal agencies have conducted extensive research and publicity programs, and recognized authorities on the economic, political, and technological problems of air pollution control have published their views and findings. At least one comprehensive synthesis of economic theory and research findings has been publicized, the work of Ridker,[1] in which he discussed the costs of air pollution damage and the frustrating difficulties that beset investigators in this area.

Several recent public-attitude surveys are of specific interest in the assessment of consumer experiences with air pollution effects on textiles. Unfortunately, no survey has focused strictly on air pollution damage to textiles, although a few have attempted to isolate the cleaning costs associated with soiling. Public information and education concerning air pollution effects on textiles is also scarce. Research findings, therefore, have been informative only with respect to the general aspects of the air pollution problem.

De Groot[2] has reviewed a series of surveys on public air pollution awareness that were conducted primarily in the early 1960's, well in advance of current air pollution publicity. In each survey, a consistently large number of respondents considered air pollution a problem in their locality. Generally, the proportion of respondents viewing air pollution as a problem increased as the level of air pollution in their community increased. Health problems were by far the greatest reason for air pollution concern. Interestingly, the respondents tended to perceive air pollution as a less severe problem in their own neighborhood than in the entire community. As De Groot suggests, a denial mechanism may be at work, for it may be psychologically demanding for people to admit to a larger problem in their neighborhood than in the community as a whole.

Undoubtedly socioeconomic factors influence public attitudes toward air pollution. In the surveys De Groot reviewed, however, the level of air pollution was found to have more influence on attitudes than home ownership, family size, age, sex, race, and income. In a more recent survey of public attitude in Johnstown, Pennsylvania, Crowe[3] found various socioeconomic factors to be associated with the public perception of air pollution. With increases in education and income, respondents defined air pollution more in terms of sources than effects. The degree of sophistication of the air pollution definition also increased with education and income. Length of residence, sex, and to a lesser extent, place of residence were not particularly associated with air pollution perceptions.

Though public concern about air pollution is growing, Rankin[4] presents some evidence that indicates public disillusionment, disinterest, or apathy toward the prospects of control and abatement. In a survey of the attitudes of residents in Charleston, West Virginia, and three neighboring communities, respondents in all communities were appreciably aware of air pollution and were optimistic that it could be substantially reduced. More than half of the respondents in each community, however, expected air pollution to remain the same or become worse over the next 5 years. More than two-thirds of the respondents were either unaware or uninformed of current governmental control programs, both at the national and local levels. Such lack of knowledge is certainly conducive so disillusionment and apathy in many segments of the population.

Closely related to public apathy concerning air pollution may be the question of priorities for solving a variety of contemporary urban problems. Issues such as education, race relations, urban renewal, mass transportation, crime, and pollution compete for public attention. Apathy toward pollution may be another way of expressing concern for more important problems. In several of the previously mentioned surveys, public perceptions of the importance of air pollution were examined in relation to other urban problems. In all four West Virginia communities surveyed by Rankin, the air pollution problem received a greater percentage of "very serious" or "somewhat serious" ratings than did problems concerning lack of recreational facilities, unemployment, race relations, juvenile delinquency, traffic, and low-income medical care. In the Johnstown, Pennsylvania, survey, however, Crowe found that problems of unemployment, traffic, and lack of recreational facilities ranked above air pollution in importance, although in the absolute sense air pollution was nevertheless considered an important problem. The overall results of De Groot's review were similar to those of Crowe; in several of the surveys, however, air pollution was recognized as a greater problem than other typical urban problems.

These surveys show that the public is well aware of the air pollution problem and rates it among the most serious of urban concerns. The public also understands that air pollution is unhealthy. Problems of personal property damage have not, however, been widely publicized. Some apathy concerning air pollution control and abatement has developed, partially resulting from the low level of public knowledge about local and national control programs.

Public Information About Air Pollution Effects on Textiles

A survey of popular national mass news media, including weekly news magazines, showed that the overall air pollution problem has received extensive publicity during the past several years. The media have hardly mentioned damage to textile products, however, except for occasional publicity given to infrequent episodes of air-pollution-induced runs in women's nylon hosiery. This lack of information for public consumption is not surprising because, in the past, knowledge of air pollution effects on textiles has not spread to any great degree beyond the confines of the textile industry. Today, however, expansion of this knowledge and understanding seems to be taking place.

Home economists and other consumer scientists are the current leaders in consumer education with respect to textile problems. Textbooks widely used in home economics education specifically discuss air pollution effects on textiles, with emphasis on gas fading of dyed acetate fabrics. Air-pollution-induced soiling and fabric deterioration, however, receive little attention. Unfortunately, home economics education does not reach all segments of the population, and the dissemination of information is therefore limited.

Among textile and apparel manufacturers, air-pollution effects are well-known. Test standards for defects caused by weathering and certain air pollutants have been established for many years. Although standards for air pollution resistance are included in many programs for product quality testing, information is not ordinarily disseminated to the general public. Occasionally, however, resistance to gas fading has been mentioned on textile product labels. This problem has also been briefly covered in some promotional and educational literature. Such point-of-purchase information will likely increase in the coming years as manufacturers take further interest in consumer education as a promotional strategy. For the present, manufacturers continue to press more for technical improvements in developing fibers and dyes that resist air pollution.

Characteristics of Textile Products

Clothing and home furnishings, while necessities of life, are influenced considerably by fashion. Style obsolescence often dictates the disuse of textile products long before physical wear life has been expended. Although air pollution effects may result from exposures as short as 1 to 3 months, more typically they will take 1 or more years to become noticeable. Often, these effects are so gradual as to go totally unnoticed. Also, some textile products, primarily clothing, may be only infrequently exposed to air pollution so that they may be discarded for fashion reasons long before air pollution effects can occur or become apparent

The difficulty in determining air pollution effects on textiles is complicated by other damage mechanisms. Sunlight, laundering, mildew, abrasion, and other damage causes may be more important than the effects of air pollution. Furthermore, air pollutants may combine with these other causes to produce synergistic effects. Consequently, it is often impossible to identify the single most important cause of damage.

Social and Cultural Influences

Surveys discussed earlier show that socioeconomic and cultural factors influence air pollution awareness and attitudes. In a society of ever-increasing affluence, many individuals may perceive little economic consequence from problems caused by air pollution. This lack of perception may be the case especially where textile products are concerned, since style obsolescence and other types of problems may have more economic importance than problems caused by air pollution.

The income factor may have real significance in public reactions to the costs of soiling resulting from air pollution. Furthermore, standards of cleanliness may vary with the ability to pay for extra cleaning. Closely related to standards of cleanliness are social class and cultural factors. In more affluent classes, it is both economically feasible and socially necessary to maintain a high level of cleanliness. Thus, additional cleaning costs become a necessary burden of some social classes, although it is a burden that falls on those who can most likely afford it. In other social and income classes, however, individuals may learn to live with increased soiling because of lower standards of cleanliness or reduced ability to absorb the extra costs, or a combination of these reasons.

Another factor affecting the importance people attach to air pollution is that air pollution competes with many other social problems for public attention. Accordingly, the importance of pollution control is frequently overshadowed by social problems such as urban renewal, education, welfare, medical care for the indigent, crime, and drug control. Furthermore, textile problems resulting from air pollution must compete with more widely recognized air pollution problems such as health effects, reduced visibility, and malodors. In this competition, damage to material products may, therefore, be considered less important than these other significant problems. These other air pollution problems generally take precedence over materials effects problems, especially textile effects.

Survey Research Techniques

Several research techniques may be useful in assessing consumer experiences with air pollution. Public opinion surveys have been the most popular method. Also, for some research questions, useful data on consumer complaints and problems may be obtained from records of retail stores, corporations, cleaning establishments, and trade associations, and from consumers' expenditure records. When available in useful form, the latter sources may be especially valuable for economic analysis. Store or corporate complaint records, however, may be of only limited use because consumers are often reluctant to register complaints even in valid cases. Consumer surveys, therefore, seem to be the most productive means of acquiring information for assessing the extent and magnitude of problems related to air pollution.

In public opinion research, the major problem is to design a questionnaire that validly measures the variables under study. Questionnaires are research instruments that, if properly developed and applied, yield scores or measures of variables that have been found to be reliable and empirically valid. Determining the appropriate variables to measure is particularly difficult in exploratory investigations. Survey researchers must design questions that the public can respond to effectively and without confusion. A number of problems come into play such as respondent or interviewer bias, overreporting bias, respondent fatigue or disinterest, poor recall or memory, and a host of other influences surrounding the interviewing situation. In theory, these biasing influences may be controlled by the use of a well-designed survey plan and of qualified interviewers. As a result, public opinion research can often yield a significant degree of statistical precision when compared to other data collection methods.

THE PHILADELPHIA SURVEY PLAN

Objectives

The primary objectives of this survey were:

1. To measure consumer awareness of the detrimental effects of air pollution on household textile products.
2. To evaluate the overall importance of household textile problems caused or potentially caused by air pollution.

Several supplementary objectives were:

1. To measure public awareness of air pollution and its associated problems.
2. To evaluate the influence of socioeconomic factors on consumer attitudes and awareness.
3. To measure the dissemination and availability of public information on the effects of air pollution on textile products.

Approach

Although laboratory research and field service trials have shown that air pollution affects textile products, no systematically documented evidence of actual consumer experiences had been collected prior to the Philadelphia survey. This project, therefore, focused on identifying textile problems that consumers directly associate with air pollution, though at the outset, the investigators realized that consumers, in many cases, would not recognize this association. Therefore, in an attempt to overcome this lack of recognition, the survey included questions on selected textile problems that previous scientific research had shown to be caused by air pollution.

Methodology for the Philadelphia survey differed somewhat from previous surveys that sought information on air pollution damage to materials. The earlier surveys assumed that damage problems were recognizable and proceeded directly to question the respondents on the frequency of occurrence, frequency of cleaning or maintenance, etc. Such information is particularly useful for direct economic analysis if the assumption is valid that individuals recognized the problems and could recall how frequently they experienced them. The direct approach, however, may not be-feasible because individuals surveyed may not accurately recall the necessary frequencies. On the basis of these considerations, the Philadelphia survey concentrated on identifying problems rather than measuring frequencies of occurrence. This research strategy may not lead to direct economic analysis of air pollution problems, but it does provide a more acceptable test for the actual occurrence or nonoccurrence of specific problems. In addition, the methodology may usefully identify problems not previously considered, thus suggesting directions for future scientific investigations.

Survey Methodology

Several key considerations entered into the decision to conduct the survey in Philadelphia. Of special interest was the fact that the city had been the scene of several important government-sponsored air pollution studies, including a recent survey to estimate residential soiling costs.[5] Philadelphia also has an active air pollution control program. A rather comprehensive data bank had, therefore, been generated for this city, enabling useful comparisons among the various studies. A further consideration was that Philadelphia has one of the most severe air pollution problems in the United States. Significant air pollutants include particulate matter, oxides of sulfur, and hydrocarbons. Though no "ideal" city exists where high levels of all potentially damaging pollutants are found, Philadelphia is among the highest in nearly all pollutants with the exception of oxidants. Nevertheless, oxidants are present at levels that can cause textile problems.

The investigators determined that a sample size of 400 would give reasonable statistical accuracy for the survey. They randomly selected the sample from the 1969 Philadelphia County telephone directory, the most accurate listing of households available. Since a certain lack of response was anticipated, an initial sample of 600 respondents was selected. As the survey progressed, it became necessary to increase the sample by 400 in order to complete 400 interviews.

For later data analysis, the investigators divided the sample into two geographical areas, based on air pollution levels. Published air pollution concentration maps[6] were used for this purpose. Although these maps were not highly detailed, it was apparent that lower levels of pollution existed in the northwest and northeast sections of the city, while higher levels prevailed in the center city area. According to their place of residence, respondents were, therefore, classified either as living in "high" or in "medium to low" pollution areas.

Analysis of 1960 census data[7] indicated considerable socioeconomic differences between the two "pollution" areas of Philadelphia. Residents in the northeast and northwest subruban sections of the city were largely white collar workers of higher income, while those in the center city area were mostly lower-income blue-collar workers. The socioeconomic differences between the two areas may have a potentially biasing effect on area-by-area air pollution awareness and attitudes. Such possibilities will be examined.

All interviews were conducted by telephone, one of the most economical methods of collecting data and quite adequate for exploratory surveys. Although telephone interviewing limits the complexity of questionnaire design and measurement techniques, a pretest of the questionnaire indicated that useful data could be obtained by this method. The use of self-administered mail questionnaires was not considered because of greater expense and typically low response rates.

Questionnaire Design

The initial survey questionnaire was designed using questions similar to those included in previous air pollution public-opinion research. Several questions focusing on the general problem of air pollution were specifically based on previous research. They were included in the first part of the questionnaire, followed by questions seeking general information on clothing and home furnishings problems that respondents may have recently experienced without regard to possible air pollution relationships. Subsequent questions concentrated directly on the association between air pollution and textile damage. Concluding questions furnished basic demographic data.

After pretesting, the questionnaire was modified to the final form presented in Appendix A. (Pretesting suggested the rewording of several questions, and a few questions were either reordered or discarded to allow a smoother sequence of questions.) The questions fall into four specific groups:

1. General air pollution awareness and attitudes (questions 3, 6, 7, and 8).
2. Experiences with various clothing and home furnishings problems, without specific consideration of air pollution effects (questions 4, 5, 13, and 14).
3. Knowledge and opinions on the association between air pollution and textile damage (questions 9, 10, 11, 12, and 15).
4. Socioeconomic and related information (questions 1, 2, and 16 through 21).

The final questionnaire represented a trade-off between comprehensive coverage of research issues and the need to limit questioning within the constraints of telephone interviews.

Field Administration

The survey was administered by long-distance telephone during a 1-month period in February and March 1970. Interviewers were given special training and experience prior to their conducting the survey. All interviewers possessed technical knowledge of air pollution effects on textiles. This background proved useful in identifying potential air pollution problems for further discussion with respondents; interviewers who were less competent technically might easily have overlooked textile problems that, in fact, could be associated with air pollution.

Interviewers made four attempts to reach each household, including evening "callbacks" to those households that did not answer during the daytime. They talked only to the female homemaker in each residence; homes unable to meet this condition were discarded from the survey. The approach of interviewing only female homemakers was based on the knowledge that women are the major consumers of textiles, both for themselves and for other family members. As "family purchasing agents," they are most likely to be both well informed of and experienced with textile problems.

The interview completion rate for the survey (Table 5-1) was not as high as had been expected. Completed interviews were obtained from only 42 percent of the initial 600 households called. A secondary sample of 400 respondents was then generated in order to complete the survey sample. Of the secondary sample, 391 respondents were called at least once in order to complete the 400 interviews desired. The overall survey response rate was 41 percent. It is noteworthy that 15 percent of the sample was disqualified because the numbers called were business phones, phones were not in service, or no female was in residence; and that 7 percent of the respondents did not provide information because of sickness, old age, or other valid reasons. If these negative responses are removed from the analysis, the survey response rate is well over 50 percent for the entire sample.

It should be pointed out that some lower income families do not have telephones and that a number of people, especially among the upper income and professional occupation classes, have unlisted numbers. Thus, sampling from a directory implies a bias in selection of income and occupation extremes in the population. The survey results, therefore, have a degree of nonresponse bias, the direction and extent of which are unknown.

Table 5-1. SAMPLE RESPONSE RATE
(percent)

Results of attempts to call	Initial sample (n = 600)	Total sample (n = 991)
Complete	42	41
Refused	25	23
Legitimate refusals	8	7
Not contacted	9	14
Business phones	4	4
No female in residence	6	6
Phones not in service	6	5

THE PHILADELPHIA SURVEY FINDINGS

Profile of Survey Sample

Tables 5-2 through 5-6 summarize the collected data, and Tables 5-7 through 5-13 test for relationships among various relevant variables through cross-classification analysis. For all tables, columns for individual topics may not always total 100 percent because (1) rounding-off errors may be involved; (2) multiple open-end responses were collected; or (3) less than the total sample was required to respond.

Table 5-2 presents a profile of the socioeconomic and related characteristics of the survey sample. All socioeconomic classes were well represented in the sample, and the distributions corresponded closely to national and urban averages for the population characteristics. The table if further broken down into "Area 1," the higher air pollution center-city area, and "Area 2," the lower air pollution suburban area. Clear socioeconomic differences existed between the two areas, primarily in education and income and, to a lesser extent, age. Socioeconomic differences between the two areas reflect the well-known migration of white collar workers from the center city to the less congested and less polluted suburban areas. The observed differences between the areas were generally in accord with those expected from 1960 census data and population projections.

Analysis of Responses Related to Air Pollution Factors

Table 5-3 summarizes several measures of various air pollution factors included in the survey. The first part of the table focuses on general air pollution awareness and attitudes, while the latter part examines specific public perceptions of the association between air pollution and textile problems. The general questions were similar to those used in previous public opinion investigations, and the findings were also quite similar. Questions concentrating specifically on air pollution textile problems were unique in this survey.

Analysis of Table 5-3 indicates considerable public awareness and concern with the overall air pollution problem. When asked the open-ended question of what problems were associated with living in Philadelphia, the two most frequently mentioned were air pollution and crime. Dirtiness of the city, which is air pollution associated, was also mentioned. Only 15 percent of the respondents actually mentioned air pollution (second only to crime, at 16 percent), but it is important that this problem was among those most frequently mentioned. About one-half of the respondents did not mention any problems.

Respondents conceptualized the air pollution problem largely in terms of transportation (auto and diesel exhausts) and industrial sources and, to a slightly lesser extent, in terms of health problems, smoke and soot, and odors. Thus, the concepts were primarily related to visible effects and odors. Only a few respondents mentioned the important gaseous pollutants such as oxides of sulfur and nitrogen. Not a single respondent mentioned effects on materials as a result of air pollution, even though soiling is a major visible effect. Furthermore, 22 percent of the respondents had no specific air pollution conceptualization. This figure may be a measure of air pollution nonawareness and, as such, may imply that more people are truly unaware of air pollution than previous analyses indicated. Overall, however, 65 percent of the respondents perceived air pollution to be a "very serious" problem in their community.

When asked if they had ever experienced problems with air pollution (not to be confused with respondents' concepts of air pollution), 46 percent of the respondents replied in the affirmative. Health and odor problems were most frequently mentioned; 4 percent of the respondents mentioned textile problems. When specifically asked, however, if they had noticed textile problems thought to be caused by air pollution, 15 percent of the respondents said they had experienced such problems. General soiling and, to a much lesser extent, specific drapery problems (color change, soiling, and deterioration) were mentioned. Also, 28 percent of the respondents perceived that the cost of textile problems caused by air pollution was at least "somewhat serious." When asked why they considered the costs "serious," respondents mentioned a combination of laundering, deterioration, and clothing-appearance problems.

The survey indicates, therefore, that only a small segment of the population was aware of the textile problems caused by air pollution. Soiling was the most obvious problem; color changes and fabric deterioration received scattered mention. Apparently the relationship between air pollution and the major textile problems caused by pollution was neither well conceptualized nor well understood by the respondents. Furthermore, compared to general public awareness of air pollution, awareness of air pollution effects on textiles was minimal.

Table 5-2. SOCIOECONOMIC PROFILE OF SURVEY SAMPLE (percent)

Socioeconomic factors	Area 1 (higher air pollution) (n=168)[a]	Area 2 (lower air pollution) (n=229)[a]	Total sample (n=400)[a]
Residence time in Philadelphia			
< 10 years	18	19	19
≥ 10 years	82	81	81
Residence time in present home			
< 5 years	31	33	32
5 to 10 years	17	23	19
≥ 10 years	52	45	49
Number of people living in home			
1 or 2	34	29	32
3 to 5	51	49	50
6 or more	13	18	15
No answer	2	3	2
Age of respondent			
18 to 29	21	21	21
30 to 39	25	27	26
40 to 49	20	23	21
50 to 59	14	15	14
60 and over	20	11	16
Refused to answer	0	3	2
Education of respondent			
Non-high school graduate	31	18	25
High school graduate	42	39	41
Some college	16	25	20
College graduate	10	17	13
No answer	1	1	1
Total annual family income			
< $6,000	24	14	20
$6,000 to $9,999	24	24	24
$10,000 to $14,999	25	26	25
≥ $15,000	9	20	14
Refused to answer	7	9	8
Not known	10	7	9
Type of heat			
Electric	7	10	8
Gas	48	60	52
Oil	29	23	26
Other	17	8	13
Air conditioners in home			
Yes	54	71	61
No	46	28	38
No answer	-	1	1

[a] Three respondents could not be classified into either Area 1 or Area 2 because their place of residence could not be located.

Table 5-3. ANALYSIS OF RESPONSES RELATED TO AIR POLLUTION FACTORS (percent)

Urban and air pollution problems	Response[a]
Problems with living in the Philadelphia area	
Air pollution	15
Crime	16
Poor schools	6
Traffic and congestion	9
Noise	5
Poor recreation	2
No specific problems (likes Philadelphia)	51
Other (dirty city, ghettos, poor shopping, racial problems, etc.)	31
Respondent concepts of air pollution	
Auto and diesel exhausts	42
Industrial wastes	32
Health problems	32
Odors	25
Dirt and dust	20
Smoke and soot	32
Haze or fog	8
Materials damage	0
Other (nothing specific)	22
Perceived seriousness of air pollution problems in respondents' communities	
Very serious	65
Somewhat serious	21
Not serious	10
Do not know	4
Respondents reporting problems specifically caused by air pollution	
Yes	46
No	54
Types of air pollution problems mentioned	
Health problems or irritations	29
Odor problems	18
Textile damage	4
Other materials damage	4
Dirtiness in general; other	8
Respondents reporting textile problems that they thought were caused by air pollution	
Yes	15
No	75
Not sure	10
Types of textile problems associated with air pollution	
General soiling	10
Drapery yellowing	1
Drapery color losses	1
Drapery soiling by soot	2
Drapery rotting	1
Other (fabric deterioration, outdoor furniture damage, extra clothing soiling, carpet soiling)	1
Perceived seriousness of economic costs of textile problems caused by air pollution	
Very serious	7
Somewhat serious	21
Not serious	60
Do not know	13
Reasons mentioned for serious costs of textile problems caused by air pollution	
Increased laundering	17
Faster clothing deterioration	14
Poor appearance of clothing	11
Other	1

[a] All percentages are based on the entire sample of 400 respondents.

Specific Clothing and Home Furnishings Problems

Early in the survey interview, each respondent was asked an open-ended question on various textile problems she had experienced in the past year. Responses are summarized in Table 5-4. A total of 34 percent of the respondents mentioned clothing problems, and 26 percent, home furnishings problems. Possibly more problems would have been mentioned in a structured interview, but open-ended questions were used to collect data on problems that would be important enough for respondents to recall immediately. Probably more textile problems exist than were documented in the survey, but it is noteworthy that nearly every currently important textile problem was mentioned by at least a few respondents.

For the most part, respondents tended to mention general clothing problems rather than experiences with specific items. A useful analysis of the colors, fibers, and causes of various clothing problems mentioned was not possible. In the absence of specific questions suggesting a possible cause-effect relationship, it is important to note that respondents did not associate air pollution with most of the difficulties mentioned; in fact, most of the problems mentioned are not normally associated with air pollution. The few clothing problems mentioned that could have been caused by air pollution were soiling, color changes and fading, and loss in useful life of nylon hosiery. Respondents gave no substantial evidence for relating air pollution to these problems, however.

Home furnishings problems were different in this respect since many appeared to be associated with air pollution, both in the type of problem mentioned and in the opinions of some respondents. Furthermore, the colors and fibers most frequently mentioned were those most susceptible to air pollution.

In designing the survey, the investigators anticipated that respondents would have trouble recalling many textile problems and, consequently, included inquiries about typical textile problems potentially caused by air pollution. Results of this analysis appear in Table 5-5. Five of the six problems surveyed involved fabric color changes, and the table includes specific colors mentioned. About one-half of all respondents said they had noticed color changes in clothing linings and in clothing that had been stored in closets. The response to the other color-change inquiries ranged from 17 to 36 percent. The largest percentage of respondents recalled specific color change problems occurring during storage. The most frequently mentioned color was blue; many blue dyes are known to be sensitive to air pollution. Blacks and purples were the next most frequently mentioned colors. Reds, greens, yellows, and browns received scant mention.

Hosiery damage was harder to assess. Given the numerous causes of hosiery damage, it is difficult to determine what constitutes an "abnormal" problem. Thirty-three percent of the respondents thought that they had regularly experienced unexplainable problems, however; several directly implicated air pollution.

Respondents were also asked if they had complained to retail stores about any of their textile problems. The results of this analysis are uniformly negative and are only briefly summarized. A total of 27 percent reported complaints other than style or fit adjustments. Complaints related largely to construction or premature fabric wear and, to a lesser extent, to colorfastness. Only one complaint, a curtain fading problem, seemed to be associated with air pollution. These results appear suspect, however, since retailers report that only about 1 percent of sold goods is returned annually. The large percentage of complaints by respondents may have resulted from the fact that they were allowed to report all complaints that they could recall, not just those of the past year. Also, retailers may not keep accurate records that reflect actual incidences of complaints. Nevertheless, some overreporting is suspected in this survey.

Consumer Information Sources

Table 5-6 summarizes consumer information sources and knowledge of air pollution effects on textiles. Only 12 percent of the respondents reported having received information about this subject. Most frequently mentioned sources were newspapers, magazines, and interpersonal communications. The type of information that respondents

Table 5-4. SUMMARY OF TEXTILE PROBLEMS DOCUMENTED IN THE SURVEY (percent)

Problem documented	Response[a]
Type of clothing problem (34% response)	
Poor general quality or wearing of garments	8
Seam ripping or construction problem	4
Durable press problem	6
Synthetic fibers problem	2
Soiling of synthetics	3
General soiling	3
Dimensional stability	2
Detergent problem	2
Washfastness of dyes	2
General colorfastness	5
Poor fabrics in boy's pants	4
Yellowing or greying problems	3
Nylon stockings do not last	1
Other (bonding, pilling, frosting, fabric rotting, knit shrinkage, clothing wears out fast in washing, etc.)	5
Type of home furnishings problem (26% response)	
Drapery color losses	9
Drapery soiling	5
Drapery rotting	2
Carpet soiling	2
Carpet color loss	5
Fading of furniture materials	2
Fading of blanket binding	1
Yellowing of drapes	2
Other (carpet wearing out, upholstery problems, general soiling, pilling, blanket wear, etc.)	4
Colors and fibers mentioned in connection with home furnishings	
Blue	3
Red	1
Purple or black	1
Green or avocado	3
Brown or beige	3
Acetate or rayon	1
Cotton	1
Wool	1
Nylon	6
Other synthetic fibers	1
Causes mentioned for home furnishings problems	
Soiling from soot or other air pollution	3
Fading from sunlight	3
Washing or detergent problems	1
Other	1

[a] All percentages are based on the entire sample of 400 respondents.

Table 5-5. RESPONDENTS EXPERIENCING SELECTED TEXTILE PROBLEMS POTENTIALLY CAUSED BY AIR POLLUTION[a]
(percent)

Survey responses	Color changes in clothing stored in closets	Color changes in clothing linings	Color changes in items made of acetate	Color changes in carpets	Color changes in curtains where not exposed to sunlight	Abnormal nylon hose damage
Problems encountered						
Yes	49	53	36	17	23	33
No	51	47	64	83	77	67
Colors mentioned						
Blues	18	15	4	1	1	-
Purples or blacks	9	4	0	1	0	-
Yellowing or greying of whites	2	1	2	0	2	-
Greens or avocados	3	3	1	2	1	-
Reds or golds	1	1	0	1	1	-
Browns or beige	1	2	0	1	0	-

[a] All percentages are based on the entire sample of 400 respondents.

received dealt mainly with fabric soiling and deterioration. The survey also showed that most respondents believed the public to be generally uniformed about the effects of air pollution on textiles. In view of the often subtle nature of the textile problems caused by air pollution, however, consumers are not likely to recognize all such problems and to learn from this recognition. Educational programs will be needed to fill this knowledge gap.

Cross-Classification Comparisons of Areas 1 and 2

Table 5-7 presents cross-classifications between Area 1 (higher pollution) and Area 2 (lower pollution) for four measures of general air pollution awareness. Differences in air pollution awareness between Areas 1 and 2 were minimal. More Area 1 residents, however, mentioned various other problems, such as crime and noise that they associated with living in Philadelphia. This result was generally expected since Area 1 respondents live in the center city, where more problems exist. The respondents' concepts of air pollution were similar in both areas, except that residents of Area 2 were more likely to mention specific transportation and industrial sources of air pollution. Virtually no differences were found between the two areas in either perceived seriousness of air pollution or experiences with problems specifically caused by air pollution.

As to textile problems, the survey detected only slight differences between Areas 1 and 2: Table 5-8 summarizes five cross-classifications. Area-1 respondents tended to report more general textile problems, but those in Area 2 were a little more likely to associate air pollution with some of their textile problems. The differences, however, are not significant statistically. Respondents in both areas, therefore, seemed to experience textile problems to about the same extent. Socioeconomic factors may have influenced these findings.

Table 5-6. CONSUMER KNOWLEDGE OF AIR POLLUTION EFFECTS ON TEXTILES AND SOURCES OF INFORMATION

(percent)

Consumer knowledge or source	Responses[a]
Information received on the effects of air pollution on textiles	
Yes	12
No	88
Sources of information	
TV	1
Radio	1
Newspaper	5
Magazine	2
Personal source	2
Do not recall	3
Kind of information received	
Fabrics wear out	3
Fabrics soil	5
Colors change	1
Nylon hose damage	1
Do not recall	5
Respondents' perception of what public knows about effects of air pollution on textiles	
Quite a bit	1
Moderate amount	7
Not much	83
Do not know	9

[a] All percentages are based on the entire sample of 400 respondents.

Socioeconomic Analysis of Air Pollution Factors

The final part of the survey examined the relationships between various socioeconomic factors and air pollution awareness and experiences. As suggested by previous investigations, socioeconomic characteristics are likely to be closely associated with attitudes. In Tables 5-9 through 5-13, various socioeconomic factors are cross-classified against selected air pollution and textile measures. The socioeconomic factors investigated included

Table 5-7. ANALYSIS OF AIR POLLUTION FACTORS: COMPARISON OF AREAS 1 AND 2[a]
(percent)

General urban or air pollution factors	Area 1 (higher air pollution) (n=168)	Area 2 (lower air pollution) (n=229)
Problems with living in the Philadelphia area		
Air pollution	15	14
Crime	20	12
Poor schools	7	5
Traffic and congestion	10	8
Noise	7	2
Poor recreation	3	1
No specific problem	45	58
Other	37	24
Respondent identification of air pollution		
Auto and diesel exhausts	39	46
Industrial wastes	31	35
Health problems	31	32
Odors	25	26
Dirt and dust	20	20
Smoke and soot	31	32
Haze or fog	6	10
Materials damage	0	0
Other	22	21
Perceived seriousness of the air pollution problem in respondents' communities		
Very serious	65	65
Somewhat serious	21	21
Not serious	8	13
Do not know	6	1
Occurrence of problems specifically caused by air pollution		
Yes	46	46
No	54	54

[a] Example interpretation: 15 percent of the 229 Area-1 respondents mentioned air pollution as a problem of living in Philadelphia, while 14 percent of the Area-2 respondents mentioned air pollution. Columns may add up to more than 100 percent because of the large amount of multiple responses.

Table 5-8. ANALYSIS OF TEXTILE PROBLEMS: COMPARISON OF AREAS 1 AND 2 (percent)

Problem classification	Area 1 (higher air pollution) (n=168)	Area 2 (lower air pollution) (n=229,
Respondents reporting general clothing problems		
Yes	36	31
No	64	69
Respondents reporting general home furnishings problems		
Yes	28	25
No	72	75
Respondents reporting textile problems that they thought were caused by air pollution		
Yes	14	16
No	75	76
Not sure	11	8
Perceived seriousness of economic costs of textile problems caused by air pollution		
Very serious	5	9
Somewhat serious	23	18
Not serious	59	62
Do not know	13	11
Respondents experiencing color changes of clothing stored in closets		
Yes	52	44
No	48	56
Colors mentioned:		
Blues	19	17
Purples or blacks	10	6
Whites (yellowing or greying)	3	2
Greens or avocados	3	2
Reds or golds	1	1
Browns or beige	1	1

Table 5-9. RELATIONSHIPS BETWEEN EDUCATION AND SELECTED AIR POLLUTION AND TEXTILE MEASURES
(percent)

Air pollution and textile measures/responses	Non-high school graduate (n=103)	High school graduate (n=164)	At least some college (n=128)
Respondent concepts of air pollution			
Auto and diesel exhausts	30	41	52
Industrial wastes	21	30	45
Health problems	22	30	41
Odors	18	30	26
Dirt and dust	17	14	29
Smoke and soot	24	35	34
Haze or fog	5	10	8
Other	34	19	16
Occurrence of problems specifically caused by air pollution			
Yes	30	45	62
No	70	55	38
Occurrence of general clothing problems			
Yes	31	33	39
No	69	67	61
Occurrence of general home furnishings problems			
Yes	22	24	32
No	78	76	68
Occurrence of textile problems thought to be caused by air pollution			
Yes	7	15	23
No	83	75	67
Not sure	10	10	10
Occurrence of color changes of clothing stored in closets			
Yes	48	52	45
No	52	48	55
Colors mentioned:			
Blues	19	24	11
Purples or blacks	9	9	8
Whites (yellowing or greying)	2	2	3
Greens or avocados	6	2	1
Reds or golds	1	1	1
Browns or beige	1	2	0
Perceived seriousness of economic costs of textile problems caused by air pollution			
Very serious	9	4	9
Somewhat serious	14	22	24
Not serious	56	63	59
Do not know	21	11	8

length of residence, number of people living in a home, age and education of respondent, and family income. Seven key measures of air pollution awareness and textile problems were investigated in detail. The overall analysis reveals some interesting relationships that support the hypothesis that socioeconomic factors may influence air pollution awareness and attitudes.

Education and Income

Of all the socioeconomic factors involved, education and income were most closely related to selected air pollution and textile measures. Table 5-9 clearly reveals that with increased education respondents showed increased awareness of air pollution concepts and problems. This was also true for general clothing and home furnishings problems, and for textile problems thought to be caused by air pollution. The survey found no such relation, however, between education and observed color change of clothing during storage or between education and the perceived seriousness of economic costs of textile problems caused by air pollution.

Income Analysis (Table 5-10) tends to support the findings of the education analysis. Respondents in the higher income category were far more aware of both air pollution and textile problems than those of lower income. As far as the problem of clothing changing color during storage was concerned, however, both income groups showed about the same response, although the lower income group was slightly more responsive in naming specific colors that faded. When questioned about the economic costs of the effects of air pollution on textiles, the lower income respondents tended to perceive the costs as more serious, although the relationship is minimal. In general the results of income and education analysis suggest that these factors may be the most significant predictors for analyzing public experiences with air pollution problems.

Age

Analysis of the influence of age, shown in Table 5-11, revealed interesting relationships. Respondents were placed into one of three age groups: 18 to 29 years, 30 to 49 years, and 50 years and older. Although differences between younger and middle-age respondents were not substantial for all survey measures of awareness, in most cases consistent differences were found between the responses of these age groups and 50 years of age and older. The younger age groups were demonstrably more aware of, and mentioned more, air pollution problems than older respondents. Likewise, they reported more problems related to general clothing and home furnishings; thought air pollution caused more of these textile problems; and showed greater concern for the economic costs associated with textile problems caused by air pollution. Age relationships were not consistent, however, for problems with clothing that changed color during storage; younger respondents mentioned the least number of such instances. Nevertheless, most of the above evidence suggests that awareness of and concern with textile problems increase through youth and middle age and then, at some point, begin to decline with older age as textile needs become less substantial. For older consumers, textile problems apparently are of less concern and are either ignored or overlooked.

Length of Residence

Table 5-12 summarizes the influence of length of residence on selected air pollution and textile measures. More respondents living in their homes for a short time (less than 5 years), compared to residents of longer periods (5 years or more), mentioned various concepts of air pollution; experienced both general textile problems and textile problems possibly caused by air pollution; and tended to attach greater significance to the economic costs of such problems. More long term residents, however, experienced problems with color changes in clothing during storage in closets. A possible conclusion is that recent residents are more aware of neighborhood problems, whereas longer-term residents have learned to accept these conditions and, therefore, mention them less frequently. Other socioeconomic factors may be influencing these observed relationships.

Table 5-10. RELATIONSHIPS BETWEEN FAMILY INCOME AND SELECTED AIR POLLUTION AND TEXTILE MEASURES (percent)

Air pollution and textile measures/responses	<$10,000/yr (n=177)	>$10,000/yr (n=157)
Respondent concepts of air pollution		
Auto and diesel exhausts	37	53
Industrial wastes	25	42
Health problems	31	30
Odors	23	31
Dirt and dust	17	26
Smoke and soot	30	37
Haze or fog	5	11
Other	25	14
Occurrence of problems specifically caused by air pollution		
Yes	41	57
No	58	43
Occurrence of general clothing problems		
Yes	32	41
No	68	59
Occurrence of general home furnishings problems		
Yes	23	32
No	77	67
Occurrence of textile problems thought to be caused by air pollution		
Yes	14	18
No	79	67
Not sure	7	15
Occurrence of color changes of clothing stored in closets		
Yes	49	51
No	51	49
Colors mentioned:		
Blues	25	12
Purples or blacks	10	8
Whites (yellowing or greying)	2	3
Greens or avocados	3	2
Reds or golds	2	1
Browns or beige	2	1
Perceived seriousness of economic costs of textile problems caused by air pollution		
Very serious	7	4
Somewhat serious	20	22
Not serious	59	65
Do not know	15	8

Table 5-11. RELATIONSHIPS BETWEEN AGE AND SELECTED AIR POLLUTION AND TEXTILE MEASURES (percent)

Air pollution and textile measures/responses	Age groups, yr		
	18 to 29 (n=83)	30 to 49 (n=189)	50 and up (n=122)
Respondent concepts of air pollution			
Auto and diesel exhausts	38	50	31
Industrial wastes	47	35	19
Health problems	30	32	32
Odors	20	31	20
Dirt and dust	22	23	13
Smoke and soot	34	35	25
Haze or fog	12	10	2
Other	18	19	30
Occurrence of problems specifically caused by air pollution			
Yes	49	53	32
No	51	47	67
Occurrence of general clothing problems			
Yes	36	41	22
No	64	59	78
Occurrence of general home furnishings problems			
Yes	27	35	13
No	73	65	87
Occurrence of textile problems thought to be caused by air pollution			
Yes	19	17	9
No	69	69	88
Not sure	12	14	3
Occurrence of color change of clothing stored in closet			
Yes	33	58	46
No	67	42	54
Colors mentioned:			
Blues	10	17	25
Purples or blacks	7	7	11
Whites (yellowing or greying)	1	3	2
Greens or avocados	1	2	6
Reds or golds	1	1	1
Browns or beige	0	2	2
Perceived seriousness of economic costs of textile problems caused by air pollution			
Very serious	5	7	7
Somewhat serious	22	28	9
Not serious	65	54	67
Do not know	8	11	16

Table 5-12. RELATIONSHIPS BETWEEN LENGTH OF RESIDENCE AND SELECTED AIR POLLUTION AND TEXTILE MEASURES (percent)

Air pollution and textile measures/responses	<5 yr (n=128)	>5 yr (n=272)
Respondent concepts of air pollution		
Auto and diesel exhausts	45	40
Industrial wastes	39	29
Health problems	38	29
Odors	29	24
Dirt and dust	29	15
Smoke and soot	31	32
Haze or fog	9	7
Other	22	22
Occurrence of problems specifically caused by air pollution		
Yes	51	43
No	48	56
Occurrence of general clothing problems		
Yes	39	32
No	61	68
Occurrence of general home furnishings problems		
Yes	30	25
No	70	75
Occurrence of textile problems thought to be caused by air pollution		
Yes	21	12
No	63	81
Not sure	16	7
Occurrence of color changes of clothing stored in closets		
Yes	51	81
No	49	19
Colors mentioned		
Blues	12	22
Purples or blacks	8	9
Whites (yellowing or greying)	1	3
Greens or avocados	3	2
Reds or golds	3	0
Browns or beige	3	1
Perceived seriousness of economic costs of textile problems caused by air pollution		
Very serious	3	8
Somewhat serious	30	16
Not serious	58	61
Do not know	9	15

Family Size

Table 5-13 shows the relationship between family size and selected air pollution and textile survey measures. In some cases, considerable differences were found between smaller and larger households. More respondents in larger households (three or more people) than in smaller households mentioned various concepts of air pollution and general textile problems. The number of respondents experiencing both general air pollution problems and textile problems believed to be caused by air pollution was about the same for both sizes of households. Larger households, however, seemed to have a slightly better perception of the seriousness of the increased costs of textile problems caused by air pollution. This fact should be expected, since larger households consume more textile products and, therefore, are more likely to experience and observe textile problems. Members of larger households may also have more opportunity to discuss various problems, including textiles, thus further stimulating awareness of knowledge of problems.

Heating and Air Conditioning Factors

A final analysis briefly explored the relationships between household heating and air conditioning factors, and selected air pollution and textile measures. Heating and air conditioning can influence the degree of air contamination in homes. For instance, air conditioners might effectively seal out pollutants in the summer, while poorly filtered gas or oil heating systems might increase household contaiminants in the winter. In fact, several respondents mentioned problems that they thought could be associated with these factors. The results of the analysis, however, were generally inconclusive on this point and warrant only brief summary.

Households with air conditioning and households with electric heating reported a slightly larger number of air pollution and textile problems than other households, thus contradicting the hypotheses stated above. The increased number of problems was most likely a reflection of socioeconomic factors, since air conditioners and electric heating systems were generally concentrated in homes of people in the upper educational and income brackets. With respect to color fading problems, differences were minimal. Respondents with gas or oil heating systems tended to report more color-fading problems, but differences were small.

Some Observations of Respondents

Of considerable interest, apart from the statistical data, are the candid and unsolicited comments made by a number of respondents. Many are of a general character, while a few are richly entertaining; some may offer ideas for further investigation. Even a respondent's most naive or off-the-record statement may suggest a promising line of exploratory investigation–a potentially serendipitous byproduct.

Appendix B presents some of the most interesting comments, quoted verbatim. These comments represent a balanced selection of the most instructive attitudes concerning air pollution expressed by respondents. The comments illustrate the kinds of information they wanted very much to give the interviewers, but which the survey's limited queries could not readily yield. Without question, these unsolicited observations, the type of comments that are infrequently recorded and reported in public opinion research, offer insights that complement impersonal statistical presentations.

DISCUSSION AND CONCLUSIONS

General Discussion

Air pollution is a recognized problem among urban Americans. Throughout the past decade, a large volume of air pollution information has been distributed to the public through national and regional mass media and by

Table 5-13. RELATIONSHIPS BETWEEN FAMILY SIZE AND SELECTED AIR POLLUTION AND TEXTILE MEASURES
(percent)

Air pollution and textile measures/responses	1 or 2 members (n=130)	≤3 members (n=262)
Respondent concepts of air pollution		
Auto and diesel exhausts	35	44
Industrial wastes	22	36
Health problems	35	30
Odors	18	29
Dirt and dust	17	20
Smoke and soot	25	34
Haze or fog	7	8
Other	25	20
Occurrence of problems specifically caused by air pollution		
Yes	43	46
No	57	54
Occurrence of general clothing problems		
Yes	24	38
No	76	62
Occurrence of general home furnishings problems		
Yes	18	31
No	82	69
Occurrence of textile problems thought to be caused by air pollution		
Yes	15	14
No	83	72
Not sure	2	13
Occurrence of color changes of clothing stored in closets		
Yes	40	52
No	60	48
Colors mentioned:		
Blues	19	18
Purples or blacks	8	9
Whites (yellowing or greying)	2	3
Greens or avocados	3	3
Reds or golds	1	1
Browns or beige	1	1
Perceived seriousness of economic costs of textile problems caused by air pollution		
Very serious	7	6
Somewhat serious	15	23
Not serious	60	61
Do not know	18	10

health organizations, conservation groups, and pollution control authorities. Various opinion surveys show considerable public awareness of the problem. Air pollution awareness has been further stimulated as a result of contemporary political and social activism that has focused on the preservation of the natural environment. In view of the wealth of evidence and increasing public concern, additional evidence that air pollution is a problem of high national priority appears to be unnecessary.

What is needed now is a more complete understanding of the specific air pollution problems that people encounter. Detailed information of this type is necessary because the costs of pollution and the benefits of abatement cannot be adequately estimated without a thorough knowledge of all relevant air pollution ramifications. Philosophically, however, the most significant air pollution costs may be those that are less well defined, such as impaired health and reduced enjoyment of life. These issues and questions are the difficult ones that investigators must assess in order to develop a complete understanding of the total air pollution problem.

Investigations of public experiences and problems with air pollution are complicated by the fact that most people may be surprisingly uninformed or unaware of specific air pollution problems. While soiling, malodors and reduced visibility are obvious problems, the less obvious effects of air pollution on materials and even some health difficulties may not be fully understood or appreciated by some sectors of our society. The Philadelphia survey has examined one of these problem: the detrimental effects of air pollution on household textile products. Although a number of textile problems caused by air pollutants have been verified by laboratory investigations, no previous study has documented public awareness and experience with these problems. The public opinion survey of 400 randomly selected homemakers in Philadelphia has, therefore, yielded some useful insights.

Conclusions

Consumer Awareness of Air Pollution Effects on Household Textile Products

In measuring consumer awareness of the detrimental effects of air pollution on household textile products, the investigators evaluated the following observations:

1. Twelve percent of the survey respondents said they had heard or read information on the detrimental effects of air pollution on textiles, but upon additional questioning concerning the type of information received only 5 percent mentioned soiling, 5 percent were unable to recall any details, and no more than 3 percent mentioned the important problems of color change or deterioration.
2. Only 8 percent of the respondents perceived that people in general had at least moderate knowledge of air pollution effects on textiles.
3. Questioned as to whether they thought air pollution caused any of their textile problems, 15 percent of the respondents answered yes; however, when asked to identify the types of problems they associated with air pollution, 12 percent mentioned soiling and only 1 percent color change or deterioration.

Since awareness must include being familiar with all major types of problems and not just the more obvious effects of soiling, the survey findings strongly indicate that consumer awareness is poorly established and generally lacking. Apparently, not more than 1 to 2 percent of all consumers are truly aware of the major air pollution effects on household textile products.

Importance of Household Textile Problems Caused or Potentially Caused by Air Pollution

The following survey observations were considered in evaluating the importance of the effects of air pollution on household textile products:

1. Respondents mentioned health (29 percent) and odor (18 percent) problems most frequently when asked to cite types of personal problems they associated with air pollution. Four percent of those interviewed mentioned problems with household textiles, however. This figure may indicate textile problems are not important, or that they are important but not cited more frequently because other air pollution problems are more important and because consumer awareness is limited.
2. When respondents were asked if they had noticed any unusual or unexpected household textile problems within the last year or so, 34 percent mentioned various difficulties with clothing and 26 percent with home furnishings. Clothing problems mainly concerned quality considerations, all unrelated to air pollution. In later questioning, however, between 33 and 53 percent of the respondents said they had noticed such problems as changes in color of clothing during its storage in closets, color changes in clothing linings, and loss in strength of nylon hosiery. Although this questioning made no reference to it, air pollution is a major cause of these clothing problems. Furthermore, the most frequently mentioned colors that underwent changes were those most sensitive to air pollution. Except under direct questioning, however, respondents failed to mention these problems, probably because these problems were not important enough for respondents to recall them and, also because other types of clothing problems (e.g., quality) were more important. Nevertheless, clothing problems potentially caused by air pollution apparently do exist.
3. Most of the home furnishings problems cited by the respondents (26 percent) concerned color changes, soiling, and deterioration, all potentially caused by air pollution. Several respondents even mentioned air pollution as a possible cause.
4. Asked to identify the types of textile problems they associate with air pollution, 12 percent of the respondents mentioned soiling, and only a handful mentioned deterioration and color changes.
5. A fairly large segment of the survey population, 28 percent, perceived the economic costs of textile problems caused by air pollution to be "somewhat to very serious."

A subjective analysis of these observations leads to the conclusion that the effects, both real and potential, of air pollution on household textiles, and especially home furnishings, are moderately important but that other air pollution related problems (health and odors) are probably more important. Soiling is the most frequently mentioned type of textile problem that people associate with air pollution; however, this response may be a reflection of limited consumer awareness of other less obvious types of textile problems–color change, fading, and deterioration.

Public Awareness of Air Pollution and Its Associated Problems

The survey found considerable public awareness of and concern for overall air pollution problems. In identifying general disadvantages associated with living in Philadelphia, 15 percent of the respondents mentioned air pollution, making it one of the most frequently mentioned problems. About one-half of the respondents did not mention any specific disadvantages. For the most part, awareness focused on the nuisance aspects of pollution, including soot, dirt, haze, and odors. Definition of the problem in terms of technical factors, such as specific pollutant gases or suspended particulates, was significantly nonexistent. Automobiles and industry were frequently mentioned as major polluters. About two-thirds of the respondents rated air quality as a "very serious" problem in their community. Almost one-half of the respondents mentioned problems specifically caused by air pollution; those most frequently identified concerned health and odors.

Influence of Socioeconomic Factors on the Survey Results

Such socioeconomic factors as place and length of residence, family size, age, education, and income appear to influence, to varying degrees, air pollution awareness and attitudes. The following observations and comments support this conclusion:

1. Respondents with more education, higher income, larger families, and a shorter length of residence generally were more aware of air pollution and associated problems and experienced more difficulties

caused specifically by air pollution. They likewise reported encountering more problems of a general nature with textile products and more textile problems thought to be caused by air pollution.

2. The younger and, particularly, the middle-age respondents also seemed to be more aware of air pollution and textile problems than older respondents.
3. A greater percentage of respondents with a longer length of residence, larger families, and of middle age reported changes in color in clothing stored in closets.
4. Respondents with larger families, a shorter length of residence, and more education attached greater seriousness to the economic costs of textile problems caused by air pollution.
5. If all the socioeconomic factors were basically equal, one would expect inner-city residents, who live where air pollution is more prevalent, to be aware of and cite more air pollution problems than suburban residents. The level of respondents' reporting of problems, however, was essentially identical in both areas. Socioeconomic factors probably entered into these findings, for the survey showed that respondents with more education and income were more aware of problems than lower socioeconomic groups. Apparently, the less aware inner-city residents cited fewer problems than actually existed, while the more aware suburban residents cited more of the problems than actually existed, thus giving the apperance that both groups experienced about the same number of problems.

Availability of Public Information on the Effects of Air Pollution on Textile Products

Public information about the potential effects of air pollution on textile products is generally lacking. Only 12 percent of the respondents reported having heard or read information on this subject, and respondents generally felt that people knew very little about it. Many suggested that published information would be useful to homemakers. Obviously, to increase consumer awareness to the point of usefulness, various trade associations, retail groups, and government agencies must launch a nationwide information program to enlighten the public.

Economic Consequences

The survey did not attempt to estimate the economic costs of air pollution damage to textiles. The data in many cases, however, indicated some economic consequences of air pollution, especially in regard to soiling problems. Respondents recognized increased laundering of textiles as the most important cost of air pollution. Extra laundering also accelerates deterioration of fabrics, thereby resulting in added costs. Twenty-eight percent of the respondents judged the added cost of textile problems caused by air pollution to be at least "somewhat serious," with increased laundering and clothing deterioration the most frequently mentioned causes of increased costs.

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CHAPTER 6

SUMMARY AND CONCLUSIONS

EFFECTS ON TEXTILE FIBERS

The effects of air pollution on textile fibers vary widely and depend largely on the chemical makeup of the fiber, kind and concentration of pollutants, and meteorological conditions. Of major concern are the problems caused by particulates and the effects of the gaseous pollutants sulfur dioxide (SO_2), nitrogen oxides (NO_x), and ozone (O_3).

Soiling by airborne particles is not only aesthetically objectionable but, more importantly, reduces the service life of fabrics because of the need for more frequent cleaning and the use of harsher detergents. These stresses contribute to a progressive loss in fiber strength. Soiling is an added problem for fabrics made from manmade fibers because these fibers acquire electrostatic charges and attract particles. Furthermore, most manmade fibers, unlike cellulosic and wool fibers, require more potent cleaning agents because they do not readily absorb water-detergent solutions. Airborne particles may also accelerate the photochemical breakdown of textile fibers, and some metallic particles may catalyze the oxidation of SO_2 into harmful acids that could attack fabrics.

Sulfur dioxide is the only gaseous pollutant known to damage textiles significantly. This fact has been shown by both field exposures to ambient levels of SO_2 and by controlled-environment chamber studies using realistic SO_2 levels. Cellulosic and nylon fibers are the most sensitive of those tested; other fibers seem to be resistant. Significant damage occurs only when moisture (high relative humidity) and, especially, sunlight (ultraviolet radiation) are present.

The effects of NO_x and O_3 appear to be insignificant. From a theoretical standpoint, however, they are potentially important because O_3 is a powerful oxidizing agent and NO_x can form nitric acid.

EFFECTS ON TEXTILE DYES AND ADDITIVES

Although sunlight is the major cause of color defects in dyed textile fabrics, air pollution has also become a prime factor. Certain dyes used on wool and cellulosic fabrics are mildly sensitive to atmospheric SO_2, but, overall, SO_2 does not pose a serious problem. This is not true, however, for atmospheric NO_x and O_3. Controlled-environment studies, together with outdoor service trials and consumer complaints, show that levels of these pollutants existing in the ambient environment can react with a number of dyes and produce noticeable color changes. Even levels found in nonindustrial and semirural areas are frequently sufficient to cause fading.

Nitrogen oxides largely consist of nitrogen dioxide (NO_2) and nitric oxide (NO), but practically all fading is caused by NO_2. This pollutant can produce color changes in vulnerable dyes (mainly blues) used on cotton, rayon, acetate, and nylon fabrics. Nitrogen dioxide can also cause a yellow discoloration on undyed white fabrics when certain vulnerable additives such as optical brighteners, softeners, soil-release finishes, and processing agents are used. High relative humidity is a critical factor in NO_x damage to textiles, especially for cotton and rayon fabrics. Major fading complaints attributable to NO_x damage, have come from families using gas-fired clothes dryers and smog areas such as Los Angeles. In addition, producers and distributors of clothing have experienced costly incidents in which large numbers of garmets have faded in warehouses.

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Atmospheric ozone produces color defects on vulnerable dyes used on cotton, rayon, acetate, nylon, and polyester/cotton permanent-press fabrics. Some of these dyes are sensitive to both ozone and NO_2, while others are resistant to NO_2 but sensitive to ozone. High relative humidities (80 to 90%) greatly accelerate ozone fading. This is especially true for cellulosic and nylon fibers; pronounced fading takes place on exposure to high humidity conditions, while little color change is noted at relative humidities below 65 percent. Color changes in permanent-press fabrics and the disastrous fading of nylon carpets are prime examples of unexpected problems caused by ozone.

General measures to alleviate or prevent fading by air pollution include the proper selection of resistant dyes and the use of quality inhibitors and additives.

CONCLUSIONS

Clothing makes up a major portion of all manufactured textile products. The life of much clothing, however, depends more on fashion and style changes than on impairment and wear. Consumers often discard their clothing within 1 to 3 years. Because of fashion obsolescence and also because most clothing is in storage more often than it is worn, air pollution in many cases does not have enough time to cause significant damage, especially if fabrics have at least minimum protection against dye fading. Therefore, while damage problems do occur from time to time, the effects of air pollution on clothing do not appear to be generally a serious problem today.

The same can not be said for textiles used in household furnishings. The life of furniture upholstery, draperies, curtains, and carpets may be anywhere from 5 to 15 years. This amount of time is sufficient for air pollutants to react and produce significant damage problems. The effects of air pollution must also be considered by manufacturers of such products as tarpaulins, cordage, awnings, and flags.

Within the textile industry, the judicious selection of fibers, dyes, inhibitors, and additives is a matter of delicate balance that management must make to achieve a desired degree of quality and performance at lowest possible cost. Air pollution plays an important role in this "balancing act." As a result of steps taken to mitigate air pollution damage, plus an increasing demand for higher quality goods, the production of fabrics sensitive to air pollutants is gradually decreasing.

In the long run, the greatest problem associated with air pollution may be an intangible loss in man's enjoyment of his property. The public may accept air pollution as a "fact of life," and may feel that nothing can be or will be done to correct it. Furthermore, people may learn to live with a problem and ignore or otherwise psychologically submerge its effects on daily living. Such apathy and cynicism are contagious and, when widespread in the population, may make the enforcement of air pollution controls difficult. This possible danger emphasizes the need to bring to the attention of the public the wide range of air pollution effects that can occur.

APPENDICES

A. QUESTIONNAIRE- PHILADELPHIA TELEPHONE SURVEY

B. UNSOLICITED COMMENTS- PHILADELPHIA TELEPHONE SURVEY

APPENDIX A. QUESTIONNAIRE-PHILADELPHIA TELEPHONE SURVEY

Respondent No. C1-3 ____________
Interviewer No. C4 ____________
Area of City No. C5 ____________

Phone No. ____________ Address ______________________________

Call	Completed	Refused	Callback	Comment
1				
2				
3				
4				

"Hello, this is (interviewer's name) of The University of North Carolina at Greensboro. I'm calling long distance on a University of North Carolina study of some problems of interest to homemakers in the Philadelphia area. Your ideas will be of great value to our study; would you talk with me for a moment?" (Establish whether respondent is the "lady of the house." Interview only the female head-of-household.)

1. About how many years have you lived in the Philadelphia area, or Philadelphia County?

   ______ Years 0 ______ 10 or more C6 ____________

2. How many years have you lived in this specific home?

   ______ Years 0 ______ 10 or more C7 ____________

3. Can you think of any problems or things you don't like about living in *your area of the city?* (PROBE–Do not read list to respondent) C8 ____________

   1. ____ Air polution
   2. ____ Vandalism or crime
   3. ____ Poor schools
   4. ____ Poor stores
   5. ____ Inconvenient shopping
   6. ____ Traffic or congestion
   7. ____ Noise
   8. ____ Poor recreation facilities
   9. ____ No specific problems
   0. ____ Other

4. Let's talk about your clothing and your family's clothing for a moment. In the past year or so, have you noticed any *unusual* or *unexpected* clothing *damage* problems, such as color fading, color changes, soiling or wearing out? (PROBE FOR INFORMATION–"By this I mean clothing that did not *last* as long or *wear* as well as you *expected*. . .")

   1. ____ Yes 2. ____ No IF YES, ask Q. 4a. C9 ____________

   IF NO: "You can't think of anything that lost its color or wore out unusually fast?"

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4a. Can you describe some of these problems to me? (Record *only potential* air pollution problems.)

Number of non-air pollution problems mentioned ____________ C10 : ________

Item	*Fiber/color*	*What and where happened; perceived cause*	
____	________	____________________	C11-17 ____
____	________	____________________	C18-24 ____

5. Have you ever noticed any *unusual* or *unexpected* damage to any of your curtains, carpets, blankets, furniture materials, or other home furnishings? (PROBE for information similar to Q. 4.)

1. ____ Yes 2. ____ No IF YES, ask Q. 5a. C25 ________

5a. Can you describe some of these problems to me?

Item	*Fiber/color*	*What and where happened; perceived cause*	
____	________	____________________	C26-31 ____
____	________	____________________	C32-37 ____

Number of non-air pollution problems mentioned ____________ C38 ________

6. Occasionally we hear the term "air pollution." When *you* hear the term air pollution, what sort of *specific things* do you think of? (PROBE–Do not read list to respondent.)

1. ____ Auto, diesel exhausts
2. ____ Industrial wastes
3. ____ Health problems and irritations
4. ____ Odors
5. ____ Dirt or dust
6. ____ Textile damage
7. ____ Other material damage
8. ____ Smoke, soot, or gases
9. ____ Haze or fog
0. ____ Other

C39 ________

7. Have you ever had any problems or complaints which you thought were specifically caused by air pollution?

1. ____ Yes 2. ____ No IF YES, ask Q. 7a. C40 ________

7a. Can you describe some of these problems to me?

1. ____ Health problem or irritation
2. ____ Odor problem
3. ____ Clothing or textile problem
4. ____ Plant damage
5. ____ Damage to other materials
6. ____ Made a complaint to some agency
7. ____ Other

C41 ________

If clothing or home furnishings problem, describe: C42-44 ________

____

8. In general, would you say that air pollution is a *very serious, somewhat serious,* or *not serious* problem in your community?

1. ____ Very serious
2. ____ Somewhat serious
3. ____ Not serious
4. ____ Don't know

C45 ________

9. Have you ever heard or read any information on the effects of air pollution on clothing or home furnishings?

1. ___ Yes 2. ___ No IF YES, ask Q. 9a-b. C46 ________

9a. Do you remember what this source of information was, or who gave you the information?

______________________________ 0 ___ Don't recall C47 ________

9b. Do you recall what information you received?

______________________________ 0 ___ Don't recall C48 ________

10. Have you ever read clothing hang tags or asked salespeople for information on the resistance of clothing to air pollution damage or gas fading? (PROBE for specific information sources sought.)

1. ___ Never searched for information
2. ___ Hang tags
3. ___ Other sales literature
4. ___ Salesperson
5. ___ Other personal source
6. ___ Other

C49 ________

11. Would you say that most people know *quite a bit, a moderate amount,* or *not much at all* about the effects of air pollution on clothing and home furnishings?

1. ___ Quite a bit
2. ___ Moderate amount
3. ___ Not much at all
4. ___ Don't know

C50 ________

12. Have you *ever noticed* any damage to clothing or home furnishings that you *think* might be caused by *air pollution*?

1. ___ Yes 2. ___ No 3. ___ Not sure (Do not know) C51 ________
IF YES OR NOT SURE, ask Q. 12a. and 12b.

12a. Can you describe some of these problems to me?

Product	*Damage noticed; how often noticed*	
		C52-56 ________
		C57-61 ________

12b. Were any of these items discarded because of the air pollution damage?

1. ___ Yes 2. ___ No C62 ________

13. Have you ever taken any clothing or home furnishing back to a retail store for any adjustment or to make a complaint?

1. ___ Yes 2. ___ No IF YES, ask Q. 13a. C63 ________

13a. What was the problem?

1. ___ Style or fit change
2. ___ Air pollution problem
3. ___ Other poor performance
4. ___ Other

C64 ________

14. **Have you ever noticed any of the following clothing or home furnishing problems? You can answer yes or no on each of these. . .**

		(1) Yes	(2) No	
a.	Clothing that fades or changes color in the closet, *even though not worn*	____	____	C65 ________
b.	Change in color of clothing linings	____	____	C66 ________
c.	Color change of clothing, curtains, or other things made of *acetate material*	____	____	C67 ________
d.	Color change of your home carpets	____	____	C68 ________
e.	Loss of strength or breaking of nylon hose *not caused by runs or snags*	____	____	C69 ________
f.	Color change in curtains *above* or *below* the window or where *not exposed to sunlight*	____	____	C70 ________

15. **In general, would you say that air pollution effects on clothing and home furnishings cause a *very serious, somewhat serious,* or *not serious money cost* to you?**

1. ____ Very serious
2. ____ Somewhat serious
3. ____ Not serious
4. ____ Don't know

C71 ________

IF VERY OR SOMEWHAT SERIOUS, ask Q. 15a.

15a. Why do you say that?

1. ____ Because of increased laundering
2. ____ Clothing deteriorates faster
3. ____ Clothing doesn't look good
4. ____ No special reason
5. ____ Other

C72 ________

16. Do you have electric, gas, coal, or oil heating in your home?

1. ___ Electric 2. ___ Gas 3. ___ Coal 4. ___ Oil 5. ___ Other

C73 ________

17. Do you have any air conditioners in your home?

1. ____ Home completely AC 2. ____ Some AC 3. ____ No AC

C74 ________

18. How many people, including yourself, live in your home with you?

____________ Number

C75 ________

19. In which of these age groups are you?

1. ____ 18 to 29 years
2. ____ 30 to 39 years
3. ____ 40 to 49 years
4. ____ 50 to 59 years
5. ____ 60 years and over
6. ____ Refused

C76 ________

20. Approximately how far did you go in school?

1. ____ Some grammar or high school
2. ____ High school graduate
3. ____ Some college
4. ____ Completed 4 or more years of college

C77 ________

21. In which of these approximate income ranges does your *total family yearly income* fall? (Attempt to obtain broad classification of *before tax* income.)

1. ___ Under $6,000
2. ___ $6,000 to $9,999
3. ___ $10,000 to $14,999
4. ___ $15,000 and up
5. ___ Don't know
6. ___ Refused

C78 ________

APPENDIX B. UNSOLICITED COMMENTS-PHILADELPHIA TELEPHONE SURVEY

AIR POLLUTION AS AN URBAN PROBLEM

"The air is not fit to breathe."

"No one seems to be bothered by air pollution too much . . . I mean they don't do anything. They say if you can live in Philadelphia, you can live anywhere. Maybe we're immune to it . . ."

"Why didn't they start worrying about air pollution a long time ago . . ."

"Most people don't get too upset about it (air pollution) because there is not too much they can do."

"I used to have some air pollution problems until I moved to the 'country' (Philadelphia suburb) . . ."

"Air pollution doesn't bother me, I live in the suburbs . . . the people in the city and slums talk about it a lot, they know more about it . . ."

"I moved to this new home to get away from the air pollution where I used to live . . ."

"There is a factory at the end of the street . . . We have complained to the mayor and written petitions (about air pollution), but they always say they will do something and nothing is done . . ."

"Factories are good for people too . . ."

"People get used to living with air pollution and don't notice the effects.

"I don't believe there is that much problem . . . the sky looks nice . . ."

"Who cares (about air pollution damage to materials)? It's an affluent society . . . health is the big problem . . ."

"I'm getting the h--- out of this filthy city . . ."

"If you want to learn about air pollution come up here . . ."

"As a mother of six, air pollution is the least of my problems . . why don't you do some research on sex . . .?"

"Why would anyone in North Carolina be interested in my air pollution problem, are you really calling long distance anyway . . .?"

MATERIAL DAMAGE

"I didn't really think of air pollution hurting materials, but now that you mention it . . ."

"This material damage problem (from air pollution) is something women don't know about, but I think I'll start watching for it now that I know it's a problem . . ."

"Black soot gets all over your clothes outside . . ."

"Soiling could be from air pollution . . . it causes a definite increase in costs . . ."

"The effects of air pollution on clothing are not serious because I really don't know . . . it could be happening and I did not attribute it to air pollution . . ."

"My nylon curtains have rotted in spots . . . something might have come in from the window . . ."

"Nylon stockings seem to deteriorate faster now . . . this is particularly noticeable now that I spend 30 minutes a day in downtown Philadelphia waiting for the bus . . ."

"One damage problem I think was caused by air pollution was my curtains fading in a very short time . . ."

"I have to wash my chair covers and curtains every two weeks because of the soot . . . they will wear out sooner . . ."

"The new materials are good, I really don't think that air pollution has any effect on clothing or home furnishings . . ."

"What am I supposed to do now . . . get all hepped up on air pollution as it affects my clothes . . .?"

"Get rid of the air pollution and you won't have any damage problems . . ."

INFORMATION SOURCES

"The girls never talk about air pollution damage, so I guess I just don't know about it . . . it may be a problem . . ."

"Women don't talk much about air pollution . . ."

"I never read anything about air pollution hurting materials; why don't you write something about it . . ."

"If you ever write a book about this study and it does not cost too much, I would like to buy it . . ."

"Scientists know a lot about the effects of air pollution on clothing and home furnishings . . . they should make more information available to the homemaker . . ."

"I've read articles on air pollution's effects on clothing . . . they made me more alert to the everyday effects . . . I think the public in general is usually unaware of the problem . . ."

"Most people know very little about the effects of air pollution on clothing and home furnishings, except in areas where everything just falls apart . . ."

"People know about air pollution effects on clothing but are indifferent to it . . . do you think they are going to do anything about it . . .?"

"I never thought about looking for information on the resistance of clothing and home furnishings to air pollution damage . . ."

"People don't know enough about air pollution damage on textiles . . . it should be publicized on TV . . ."

"People just agitate a lot about air pollution . . . they don't know too much about it . . ."

"I've read so much about air pollution I don't want to see any more . . ."